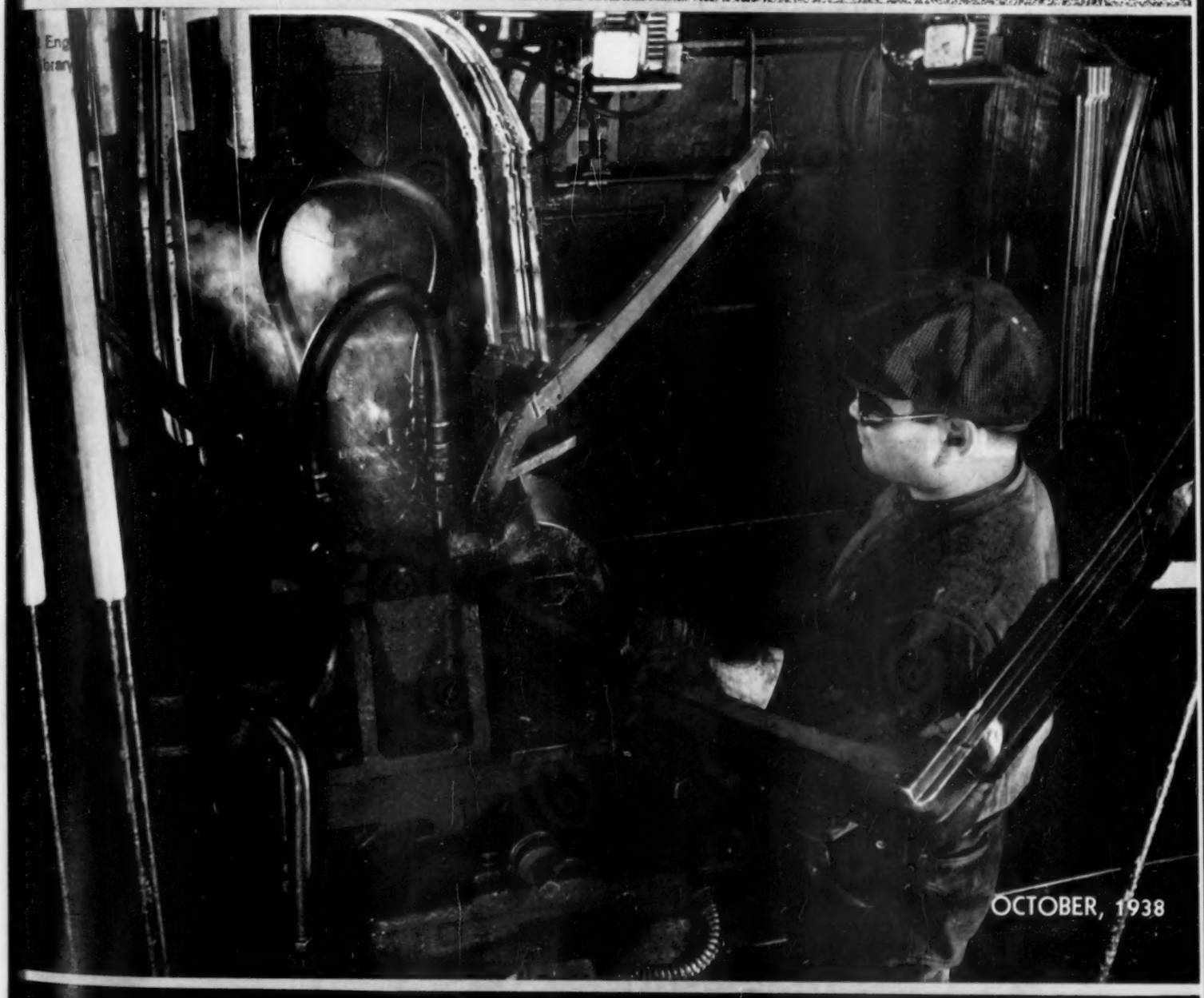
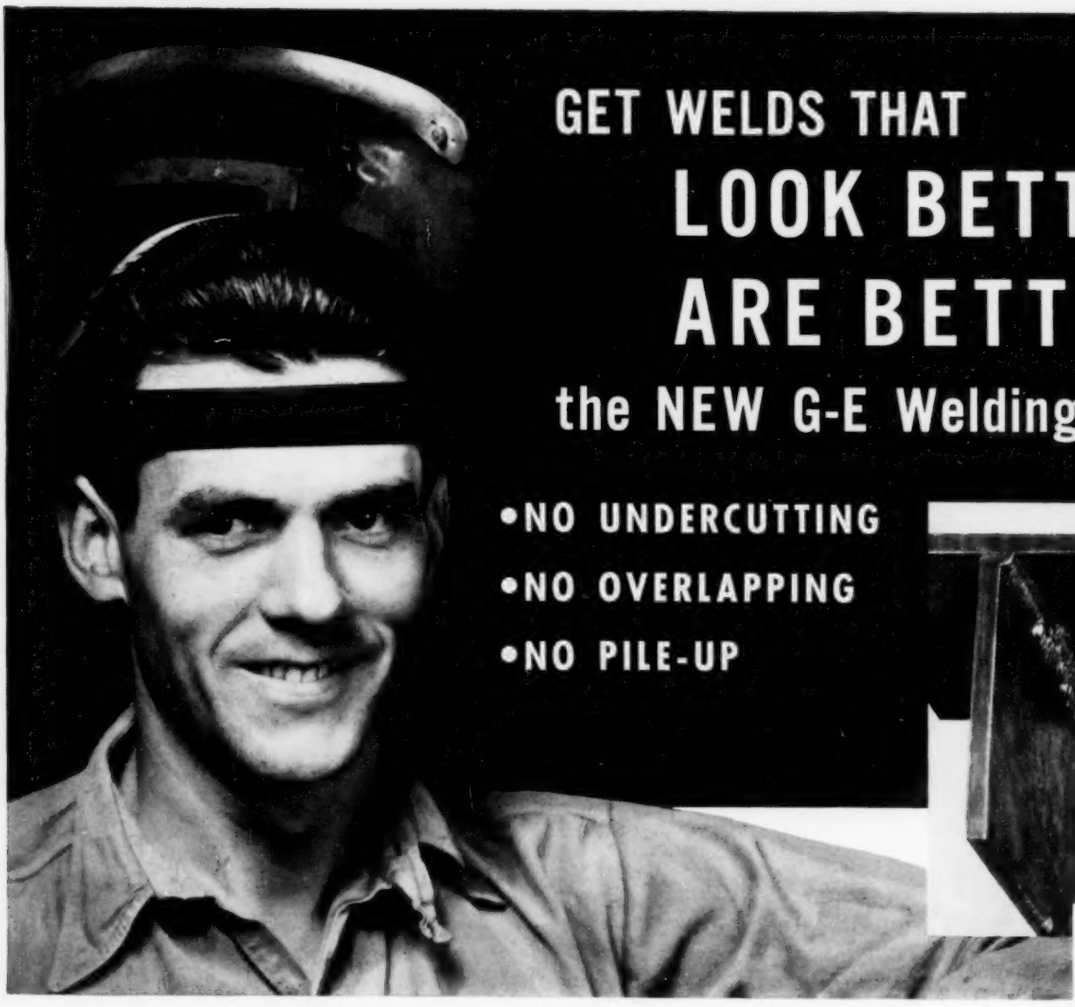
# The Welding Journal



OCTOBER, 1938

The Journal of the American Welding Society

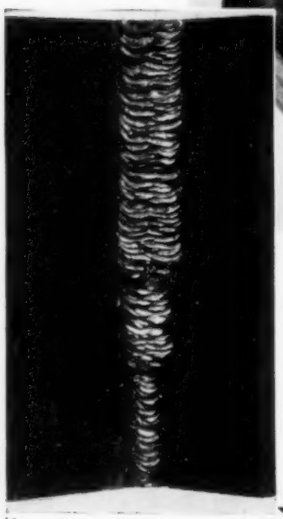


# GET WELDS THAT LOOK BETTER and ARE BETTER with the NEW G-E Welding Electrodes

- NO UNDERCUTTING
- NO OVERLAPPING
- NO PILE-UP

Typical appearance of single-pass and multipass overhead fillets made with new G-E electrode, Type W-20E

Typical appearance of single-pass and multipass fillets made in the flat position with the new G-E electrode, Type W-24



Typical appearance of single-pass and multipass vertical fillets made with the new G-E electrode, Type W-22E

IN these days of streamlining, the value of eye appeal has become increasingly important. Modern welding not only has to *be* good—it also has to *look* good. General Electric recognizes this need and has designed its new line of electrodes accordingly. Welds made with them *look* good and *are* good—as shown by a glance at the excellent appearance of these typical samples.

Their appearance proves that the electrodes actually helped the operator to lay down uniformly sound weld metal, and that he was not handicapped by having to fight against undercutting, overlapping, or piling up of the deposit. Obviously, such appearance also helps to create preference—a *real* preference—for the welded product.

Many other advantages are also obtained by users of the new G-E electrodes. The remarkable new coating permits the use of higher currents—hence faster welding speeds; the unusually high ductility and impact resistance obtained helps to avoid stress concentrations and to withstand heavy shock loads; spatter* is minimized; and there are many other points of excellence.

But you don't have to take anyone's word for these claims. Try these rods. Call the nearest G-E arc-welding distributor or G-E sales office for samples. Or send the coupon to General Electric, Schenectady, N. Y.

**As a further aid in obtaining excellent appearance and in saving time, especially on work which is to be painted or otherwise finished, use G-E Glyptal No. 1294 to prevent weld spatter from adhering to or marring surfaces adjacent to the weld. It's new.*

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**GENERAL ELECTRIC**

*General Electric Co., Schenectady, N. Y.*
*Dept. 6B-201*

*Please send me samples of your new welding electrodes.*

*Name* .....

*Firm* .....

*Street* .....

*City* ..... *State* .....

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## ANNUAL MEETING PAPERS, AMERICAN WELDING SOCIETY

**PRESIDENT'S RECEPTION SUNDAY, OCTOBER 16th,** Afternoon—5 to 7 P.M.
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**MONDAY, OCTOBER 17th,** Morning—9:30 A.M.
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Mayor of City of Detroit
**PRESENTATION OF MEDALS**

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### WELDING IN CONSTRUCTION WORK

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by A. N. KUGLER

**Single Pass Electric Welding of Unfired Pressure Vessels***
by R. M. WALLACE

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**ISSUED MONTHLY**



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Welding Journal

VOLUME 17, No. 10 OCTOBER 1938

Fig. 1—A Modern 12 Yard Carryall Scraper Loading Itself

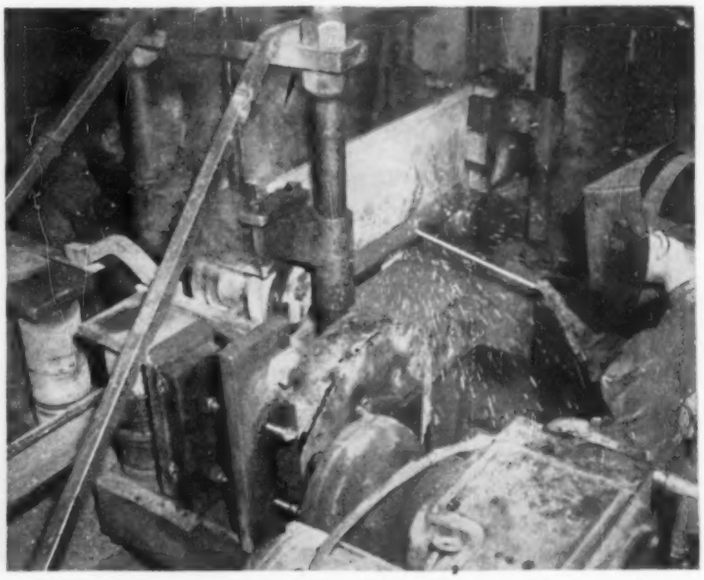


Fig. 2—Box Beam Traveling Through Tack-Welding Machine. Angles Entering Aligning Rolls at Lower Left

# ARC WELDING ROAD EQUIPMENT*

By ELMER E. ISGREN†

THE super-highways of today own their rapid, low-cost construction to the use of large modern tractor-operated road building equipment. Hills and gulches have been eliminated with the result that the highways of today are flat, straight and safe. Low-carbon alloy steel and the modern arc-welding process have done much to make this possible.

Of all the equipment used in road building, the Carryall scraper contributes more to the actual building of the road than any other one piece of equipment. These Carryall scrapers are built in sizes with a capacity of 3.5 to 30 cubic yards. Drawn by tractors, they load themselves and carry their load to where the dirt is to be deposited (see Fig. 1). The scraper then unloads itself and at the same time spreads its load uniformly. Units of this type, regardless of capacity, are subjected to tremendous shock, impact and torque stresses.

Throughout the entire building of a scraper, box type construction is employed. This type of construction produces great strength, rigidity and resistance to torque. The box beam, being a most simple member, yet so very important in the construction of these units, is fabricated on a production basis. They are produced in

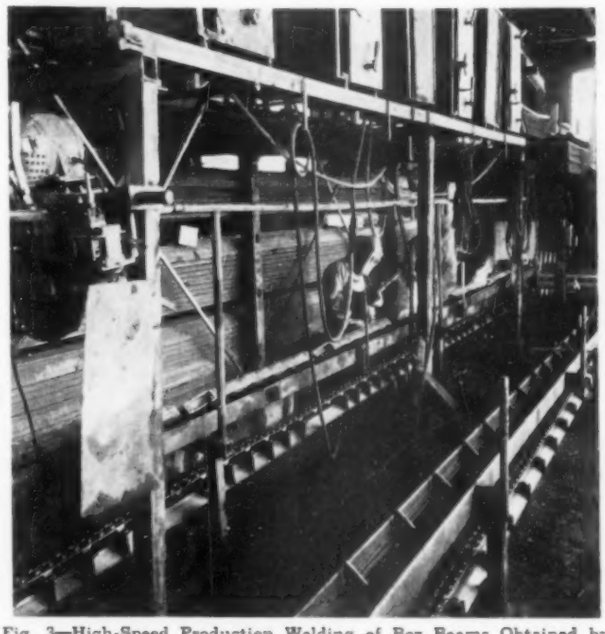


Fig. 3—High-Speed Production Welding of Box Beams Obtained by Conveyor System

* Paper to be presented at Annual Meeting, A. W. S., Detroit, Mich., Oct. 16 to 21, 1938.

† Plant Supt., R. G. LeTourneau, Inc., Peoria, Ill.

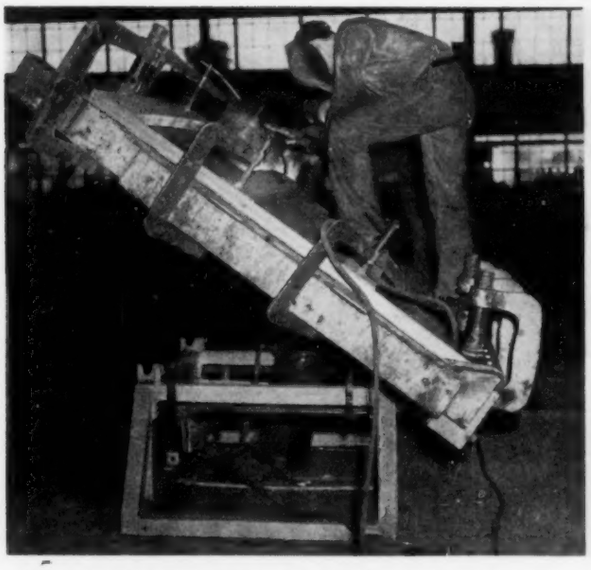


Fig. 4—Air-Operated, Four-Way Positioning Substructure Fixture Designed to Hold Distortion to a Minimum

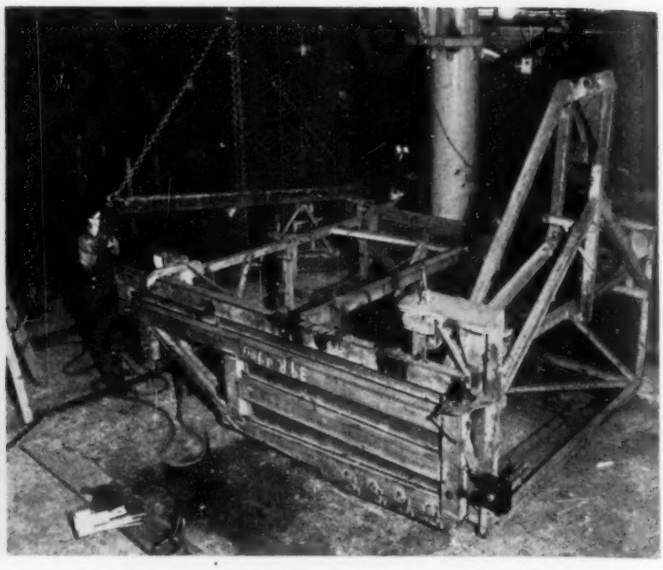


Fig. 5—Substructures Being Placed in and on Body Fixture Prior to Unification by Arc Welding

a variety of sizes and shapes—they may be 2 x 2 x $^{3}/_{16}$ inch as large as 8 x 8 x $^{1}/_{2}$ inch. They may be long or short, straight or curved. Straight box beams are fabricated from angles; while the curved sections are fabricated from four pieces of plate: Two are flame cut to give the type of curvature desired and two are standard rolled bars formed to the desired radii in a set of plate-bending rolls. Since the type of box beam most extensively used in the manufacture of our product is box beam made up from standard rolled angles, a production system has been developed to produce them.

In fabricating the beams of angles, the latter are placed edge to edge in a low-speed conveyor for the tack welding. The section is held securely in alignment by rolls at sides as well as top and bottom (see Fig. 2). The travel is through a booth. An arc-welding operator on either side applies tack welds to the seams at six-inch intervals. The sections are tack welded into 30-foot lengths. Following tack welding, the 30-foot lengths are cut into shorter pieces as required in production. Square cut beams are cut by hacksaws. Bevel cuts are made by flame cutting.

The finish welding of the beams is also done with the aid of a slow-speed conveyor which carries the work past operators (see Fig. 3). The speed of travel is adjusted to suit the size of the beam being fabricated. The heavier sections require more weld, therefore travel at a slower speed.

Skip welding is employed in the finish welding to avoid any possible distortion. The welding is done by three operators on short sections; and four on long sections. The first operator skip welds one side of the beam by laying about 10-inch beads and then skipping about 10 inches and so on for the entire length of the beam. The second operator turns the beam over and does the same to the other side. Continuing on the same side, the third operator fills in the skips. The fourth operator completes the welding by turning the beam over and filling in the skips.

Curved box beams are fabricated in fixtures designed especially for that part. These fixtures are of the all-positioning type allowing down-hand welding for the entire length of the beam.

In the construction of the scraper there are seven major welded structures or assemblies; namely—the body, yoke, front axle, push beam, wheels, tail gate and front apron. Each structure is a complete rigid unit

Fig. 6—Rapid Production Made Possible by Use of Simple Fixture Allowing Down-Hand Welding

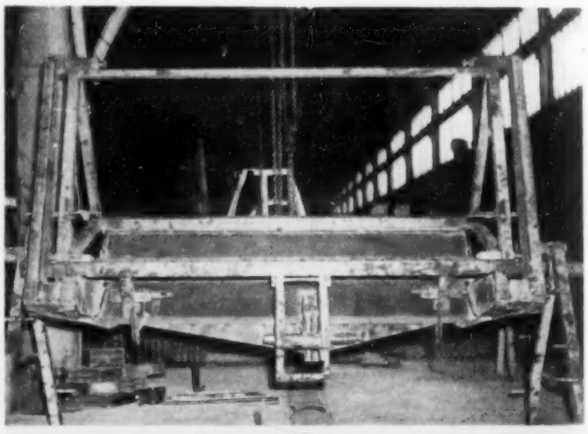


Fig. 7—Completed Wheel (Upper Left) and Component Parts

constructed of small substructures and parts assembled and arc welded in fixtures.

The body structure consists of six major substructures. These are made up of standard plate and roll sections, flame or shear cut which are placed in fixtures and welded. These fixtures are designed to hold distortion, due to welding, to a minimum and to facilitate all down-hand welding. A good example of a substructure in the process of fabrication is seen in Fig. 4. On completion of fabrication, all substructures of the body are placed in and on a fixture that holds them in perfect alignment (see Fig. 5). In addition to accomplishing this important requirement, it affords better and quicker fit-ups.

In order to hold welding costs to a minimum, all welds are completed that can be made down-hand while the fixture is in the body. The fixture is then removed and the body turned completely over by the use of an overhead crane, to accommodate down-hand welding on the bottom side. Figure 6 shows the apron structure in its assembly and welding fixture.

The body being the major part of a scraper serves as an example of our regular procedure in the fabrication of all the other structures, with the exception of the wheels.

The wheels are made in a variety of sizes and since they are required in large quantities, a rapid production set-up has been developed. The hub, disk, rim and tire ring, constitute a wheel structure (see Fig. 7).

To maintain light weight and from an economical standpoint, the hubs are made by rolling two pieces of bar steel. One is rolled just under the size of the larger bearing seat and one for just under the size of the smaller bearing seat. These two rings are then welded together and machined inside to take the bearing races; outside to receive the disks. Both ends are faced.

The disks of the wheels are cut on a rotary shear; the center hole punched in a punch press. They are dished to various depths in a hydraulic press, the depth of the disk varying from one to four inches, depending upon the size of the wheel in which the disk is to be used. They are welded to the hubs in a rotating fixture that allows down-hand welding on all joints. The outsides of the disks are then turned to true size and holes are drilled and tapped for hub caps. The bores to receive the bearing races are also reamed at this stage as the welding of the disks onto the hub causes out of roundness of the bores.

The next step is the application of the rim which is welded to the disks. The rims may vary in width from 6 to 33 inches depending upon the type of wheel being fabricated. A $^{5}/_{8}$ by 1-inch ring is welded to the outside of the rim which later machines to form the tire locking ring groove. The stationary tire rings are then welded on.

The finished structures are then moved to the final assembly line where they are mounted on and to the body. This assembly is accomplished by pins and bolts, completing the scraper. It will be noted that all structures are one solid unit unified by arc welding and no part of a structure is readily removable without the aid of a cutting torch. Yet, by removing a few pins and bolts, any one complete structure of the scraper can be easily removed.

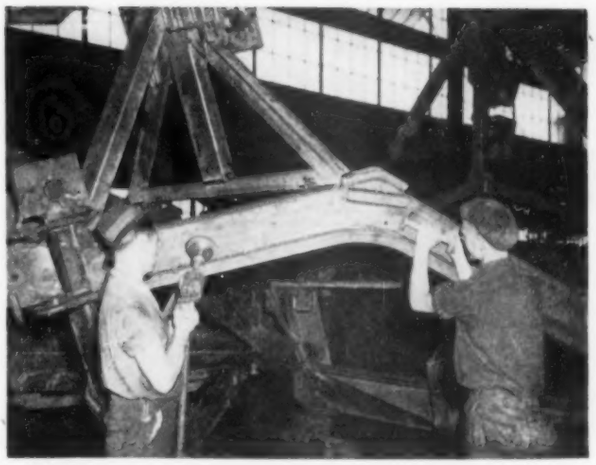


Fig. 8—A Thorough Cleaning Job in Progress on a Completed Scraper

The above information stresses only the application of production on a large scale to an all-welded product. The success of a good product and its rapid production is dependent upon efficiently trained operators who have been trained to weld on this particular type of work.

The inspection department plays an important rôle by constantly striving for welds that are free from undercut and deposited to a specified size as called for on the drawing. The AMERICAN WELDING SOCIETY weld symbols are used on all structure drawings.

A department that receives very little credit, but which plays an important rôle in the production of welded equipment, is the cleaning department. Their duty is to remove all slag and scale from the welds (Fig. 8) and prepare the unit for its coat of paint. A good cleaning job eliminates paint deterioration, consequently enhancing the appearance of the finished product.

The welding of small parts on a production basis has been an accepted practice for a number of years; however, industry has been slow in recognizing the merits of fabrication by welding of large, heavy-duty equipment on a rapid production basis. The general impression has been that it was expensive and not adaptable to production methods. It can readily be seen from the foregoing that when properly applied, regardless of size or shape, welding can be treated as any other means of unification.


## CODES, STANDARDS AND SPECIFICATIONS

AMERICAN WELDING SOCIETY

33 WEST THIRTY-NINTH STREET, NEW YORK, N. Y.

| | Price per Copy |
|---|---|
| Code for Fusion Welding and Gas Cutting in Building Construction | 25¢ |
| Specifications for Design, Construction, Alteration and Repair of Highway & Railway Bridges by Fusion Welding Non-members $1.00 Members | 75¢ |
| Tentative Standard Qualification Procedure | 25¢ |
| Tentative Specifications for Filler Metal for Use in Fusion Welding | 25¢ |
| Welding Symbols and Instructions for their Use | 25¢ |
| Rules for Welding of Gravity Tanks, Tank Risers & Towers | 25¢ |
| Rules for Welding of Oil Storage Tanks | 25¢ |

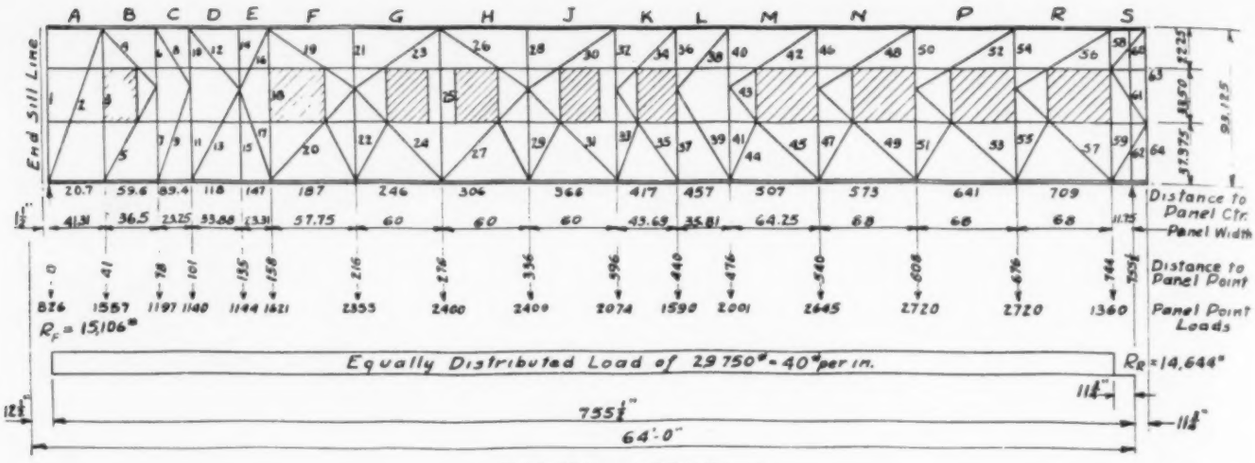

A B C D E F G H J K L M N P R S
End Sill Line
Distance to Panel Ctr.
Panel Width
Distance to Panel Point
Panel Point Loads
Equally Distributed Load of 29750# = 40# per in.
$R_R$ = 14,644#
64'-0"

Fig. 1—Diagram of Side Frame

# ARC WELDING OF TRUSS TYPE Railroad Car*

By A. M. UNGER†

THE great majority of railroad passenger cars in operation today have sides of a girder type. There are longitudinal members at the side plate, window header, belt rail and side sill which serve as stress members for vertical loading and these combined with the side posts and the outside girder sheet take care of the vertical loading plus longitudinal impact forces.

The girder sheet has an appreciable value only for the portion of the sheet near the post and longitudinal members. At the center of the panel when panel spacing is of considerable size, the forces acting on the girder sheet are small.

Much research and development has taken place over a number of years to produce lighter cars of equivalent strength and in the last four or five years this work has been highly intensified.

The reduction of weight is needless to say, extremely desirable both from an economic and operating standpoint. The girder type of side frame is at some slight disadvantage from a weight saving standpoint inasmuch as the stresses throughout the whole area of the girder sheet are rather low, being concentrated near posts, stiffeners and longitudinal members; however, this disadvantage is more theoretical than actual as this difference between the two is very small and is practically lost sight of in the finished structure.

The truss side frame has been developed on the basis that all the framing members can be so placed and so proportioned that they are stressed uniformly throughout the complete area of these sections. Very thin side sheets can be applied which do not have to withstand any stresses. The weight saving depends on the extent to which the side sheet can be reduced in thickness and still produce the necessary protection from the weather, etc.

A side frame of this type was designed for testing, using low-alloy high-tensile steel. With this material as a basis, the frame was designed so that tension and compression members were stressed to the permissible safe stress per square inch. Due allowance was made for all forces acting in these members in designing the various sections of the truss frames.

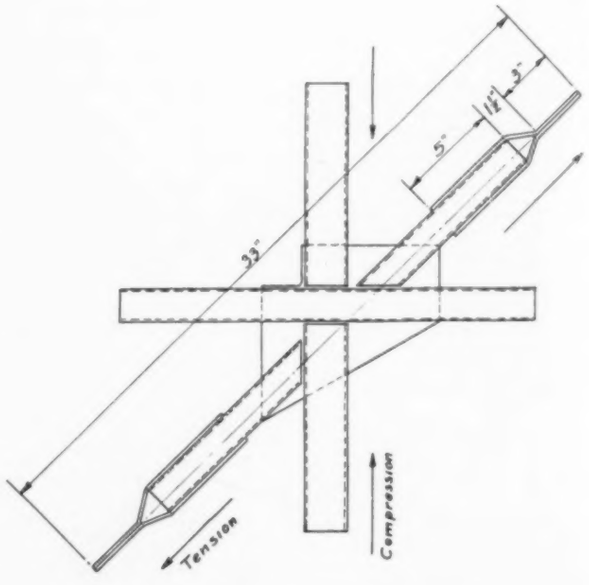



Fig. 2—Arrangement of Specimen for Test

The design of structure was based upon welding of all members since this eliminated the necessity for overlapping any of the framing members, resulting in a saving in weight of all overlapping joints and rivet heads which are found in riveted structures. Another reason for welding was that stress could be transferred from one member to another in a more direct line, thereby eliminating the necessity of heavier sections to reduce concentrated stresses that resulted from indirect transfer of stress.

The general design of a test truss is shown in Fig. 1. This frame is designed for a car articulated at one end

* Paper to be presented at Annual Meeting, A. W. S., Detroit, Mich., Oct. 16 to 21, 1938.

† Welding Engineer, Pullman-Standard Car Mfg. Co., Chicago, Ill.

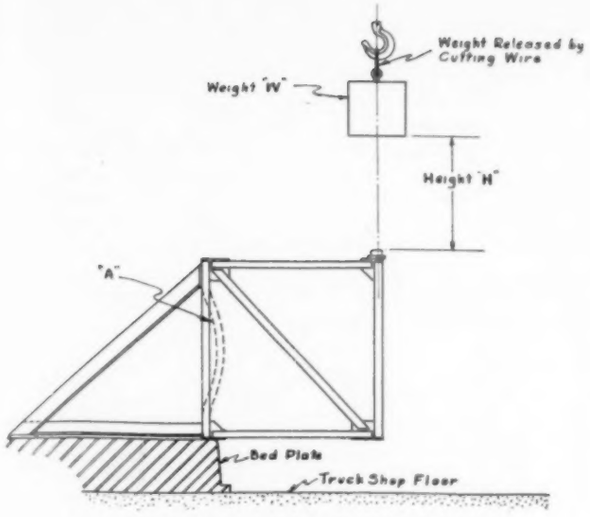



Fig. 3—Arrangement of Frame for Test

and with a pivot truck at the opposite end. The truss, as actually built for test purposes, did not have the overhang at the rear end, as this was unnecessary in the investigation. The truss structure itself was formed between the top and bottom chord members, consisting of a side plate and side sill. These two members are both "Z" shape, continuous the length of the frame. Posts are channel-shaped members extending from side sill to side plate. Diagonal members, both tension and compression, are channels with re-entrant flanges. The design of the structure utilizes the posts and braces together with top and bottom chords as the load-carrying members. All of the main members of the structure are 3 inches deep, and the gage of the steel varies, depending upon the load imposed on the individual members.

The sheathing for this frame can be made of either stainless steel or low-alloy steel. In the cars, thus far built, stainless steel has been used. The sheathing is made on a drawbench and is used in strips full length of the car, both above and below the windows with pressed panels in the window piers. The sheathing runs horizontal and is fastened to the auxiliary members of the truss with bolts, having lock nuts secured to the framing members. The design and application of the mouldings will permit any one piece being removed and replaced without disturbing other sections or the inside finish of the car.

## PRELIMINARY TESTS

Before actually making a truss side frame, experimental work was done on the type of connection to be used. Sample joints were made up and tested by pulling in a tension machine. The type of sample used is shown in Fig. 2. All of the joints failed well outside of the weld, showing that the welded joint was capable of carrying the full load of the tension member and would have at least an equal value in compression.

In order to check the ability of this type of frame to withstand vertical impact loads, a sample frame was made of shaped members and gussets entirely of low-alloy steel and completely arc welded into the structure as shown in Fig. 3.

This frame was then mounted, as also shown in sketch, so that a measured weight suspended above one corner of the frame, could, in falling free, strike a blow on this corner. After each blow the frame was carefully inspected for any deformation of members or any failure of weld-metal.

Deformation finally occurred at the point marked "A," the vertical member buckling as shown by the dotted lines.

The table below lists the blows given the frame and their effects. At no time was there any failure of weld-metal in the frame.

| Blow No. | Weight "W" | Height "H" | Change in Frame After Blow |
|---|---|---|---|
| 1 | 75 lb. | 1 ft. 0 in. | None |
| 2 | 75 " | 2 " 0 " | " |
| 3 | 75 " | 3 " 0 " | " |
| 4 | 210 " | 1 " 0 " | " |
| 5 | 210 " | 2 " 0 " | " |
| 6 | 210 " | 3 " 0 " | " |
| 7 | 210 " | 2 " 0 " | " |
| 8 | 210 " | 3 " 0 " | " |
| 9 | 210 " | 4 " 0 " | " |
| 10 | 210 " | 5 " 0 " | " |
| 11 | 445 " | 2 " 6 " | " |
| 12 | 445 " | 2 " 6 " | " |

| Blow No. | Weight "W" | Height "H" | Change in Frame After Blow |
|---|---|---|---|
| 13 | 445 lb. | 2 ft. 6-in. | Deformation at "A" |
| 14 | 445 " | 2 " 6 " | Increased Deformation at "A" |
| 15 | 445 " | 2 " 6 " | Increased Deformation at "A" |

From the evidence of this test, welds on low-alloy steel structures were shown capable of withstanding as much shock as the shaped members if the correct proportions of each are observed.

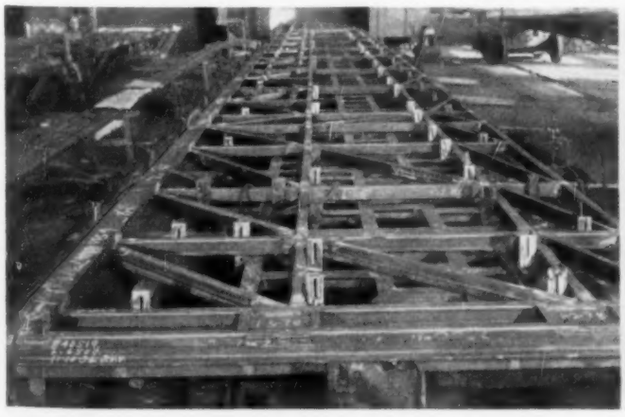


Fig. 4—Jig for Welding Side Frame

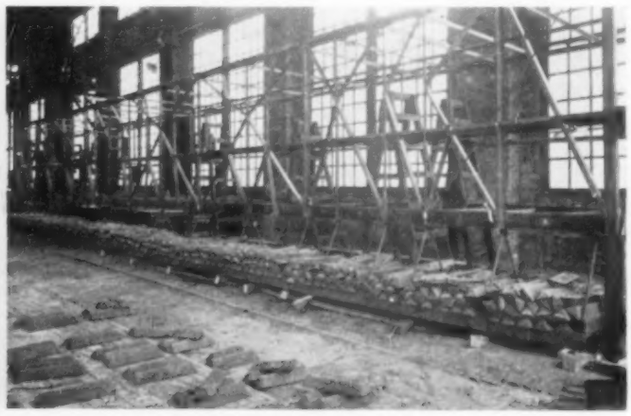


Fig. 5—Side Frame Set-Up for Test Purposes

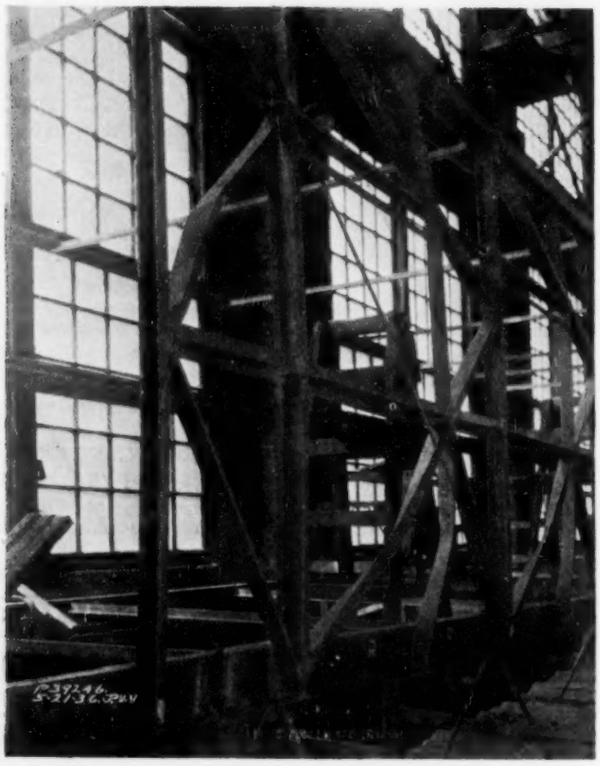


Fig. 6—Failure of Side Frame After Test

## EXPERIMENTAL SIDE FRAME

Following the preliminary tests, a special jig was built and members of the truss assembled and welded in this jig. A view of this jig is given in Fig. 4 (a description of which will be given later).

Before any welding was done, extensometers were placed on various members to determine whether any residual stresses would be left in the members due to the welding. When side frame members were laid out and fitted, prior to welding, all intersections of main members center lines were punch marked to check the shape of the structure throughout manufacture. Measurements were taken of the punch marks and checked from time to time as welding progressed. It was found that both distortion and residual stresses, due to welding, were negligible.

Following the assembly, the frame was set up for test purposes, as shown in Fig. 5. It was supported on two pedestals which were anchored to concrete bases. These pedestals supported the side frame in a manner similar to the support it would obtain at an articulated end sill and body bolster of car. To obtain horizontal stability, the frame was tied to the wall of the test building at each point at the side sill where a cross-bearer or floor pan would be located, and at side plate to each point where carline would be located. Each of these horizontal supporting members were hinged to permit deflection of the side frame under load without influencing it in any way. A platform extending the full length of the side frame was suspended under the frame from brackets welded to the side sill at the points where cross members of the completed car would be located. The test load of pig iron, each pig of which was weighed and stenciled with its exact weight, was placed on the platform as required by the tests.

After the frame was set up preparatory for the tests, two piano wires were stretched, one along the side sill and one along the side plate, to measure vertical and horizontal deflections, due to the test loading. Extensometers were applied to a number of the more important load-carrying members to check the stresses. The members on which the extensometers were applied were those which, according to the calculations, were highest stressed. The weight of the platforms supporting the load was equal to 25% of the static load on the side frame. This load remained on the frame during all of the tests. Subsequent loads and tests were applied in increments, and the extensometer and deflection readings were taken between each increment of load in both loading and unloading in the following tests:

1. Initial loading to 125% in 25% increments and unload to 25% in same increments.
2. Load individual panels up to 125% in 25% increments and unload to 25% in same increments.
3. Overload test—Load up to 200% by 25% increments up to 150%, then two increments of 15% and two of 10% and unload to 100% in same increments.
4. Overload test to breakdown—Starting with 100% load on frame, load applied to 200% load by two 25% increments, two 15% increments, and two 10% increments. After this, load was increased by 10% increments to failure of the frame.

At 210% load in the final tests, diagonal No. 57, a compression member, showed signs of twisting. At 220% load, this member twisted badly. When at 225% load, diagonal No. 61 failed in compression by buckling and resulted in other members of the truss at this end of the frame twisting and distorting. Prior to the failure of diagonal No. 61, it was noted that one or two of the tension members, such as No. 4 were stressed slightly beyond the yield point of the material.

The condition of the side frame at the conclusion of the tests is shown in Fig. 6, which illustrates the failure of the various members. The deflection of the frame under various loads is shown on curve in Fig. 7 for the side sill.

As mentioned previously, the frame was designed to stress the various members up to a safe working stress

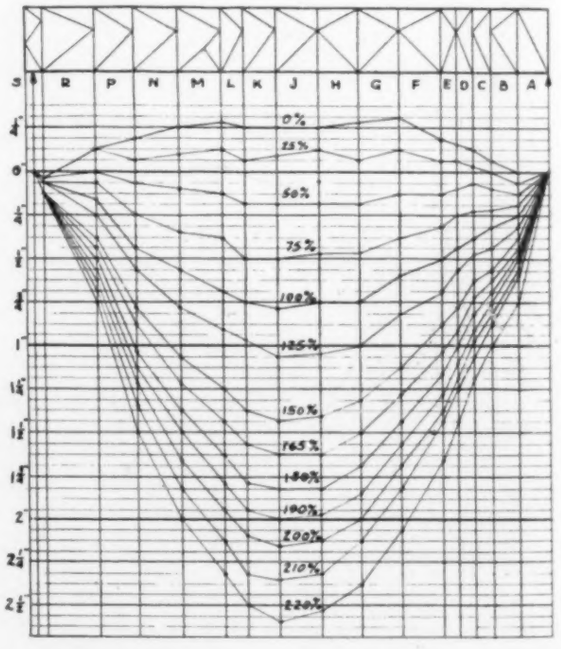
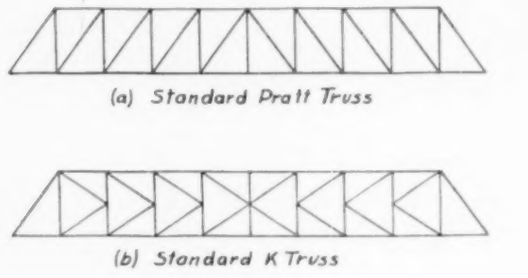



Fig. 7—Experimental Side Frame—Side Sill Deflections. Note: 0% Represents Dead Load of Side Frame Only

with the intention of checking closely the relation between actual stresses and calculated stresses. The point at which the frame started to fail indicated clearly that the actual strength of the frame corresponded very closely to the calculations, and is more than twice as strong as required by the maximum load that it will ever have to carry.

## TYPE OF TRUSS

Figure 8(*a*) shows an ordinary standard form of Pratt truss. This standard form cannot be used for a car side, as it is necessary to have open space for windows. The diagonals would interfere. Figure 8(*b*) shows a standard "K" truss that can be easily adopted for window open




(a) Standard Pratt Truss

(b) Standard K Truss

(c) Window in Panel of K Truss

(d) Modification of K Truss for Wide Window

(e) Type of Truss used in Sides of Coaches with Wide Windows & Narrow Piers

Fig. 8—Types of Trusses

ings as shown in Fig. 8(*c*) and 8(*d*). Figure 9 shows a section of side of this construction. For extra wide windows, it is necessary to modify the "K"-truss to obtain the proper clearance. Sketch 8(*e*) shows the type of truss used when large windows and narrow piers occur together. This design is actually a truss above and below the window openings. Figure 10 shows a car of this construction.

## WELDING JIG

Figure 4 shows the side assembled in the welding jig. This jig holds the side in a horizontal position. The surface of the jig is level. The outside of the side frame is assembled in the down position, that is, against the face of the jig, so that it will be in alignment to take the outside sheathing.

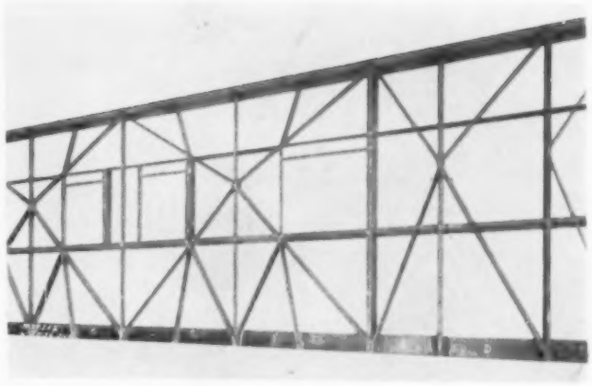


Fig. 9—Section of Side Construction

Gussets are welded to the vertical posts in sub-assembly. In this side jig, the diagonal members are welded to the gussets, and all other welding is completed. Practically all of the welding is fillet welding, due to the design of the connection. A cross-section of a framing member showing attachment to gussets is shown in Fig. 11. With this design of connection, there is an even distribution of stress from member to member through the gusset. This is especially valuable in a compression member. The load is carried primarily by the corners. The load is nicely transferred from the gusset to the corners of the member through the fillet welds which join the two together.

Another advantage of a gusset connection of this type is that by its use all welding on important stress members can be made longitudinal to the member. This eliminates stress concentrations and residual stresses due to transverse welds.

The fits for welding are good, because of the design of the connection. The top side is welded first, then the whole side is turned over for welding of the reverse side. All members are held in the jig by a special clamp which holds them in alignment and firmly against the face of the jig. This clamp uses a wedge for fastening and can be seen in Fig. 4.

## UNDERFRAME

The underframe of the car is entirely of arc-welded construction The center sill is composed of two Z-

Fig. 10—Showing Side Construction per Sketch 8(*e*)

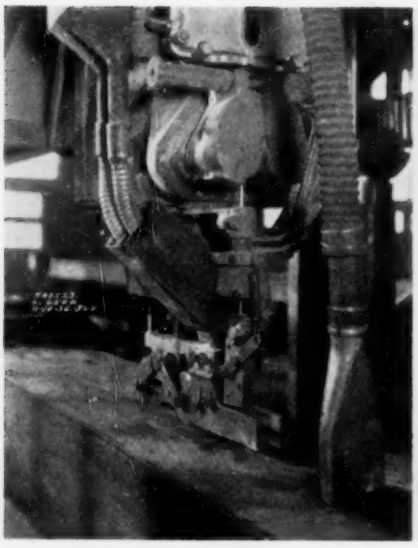


Fig. 12—Union Melt Machine Welding Center Sill

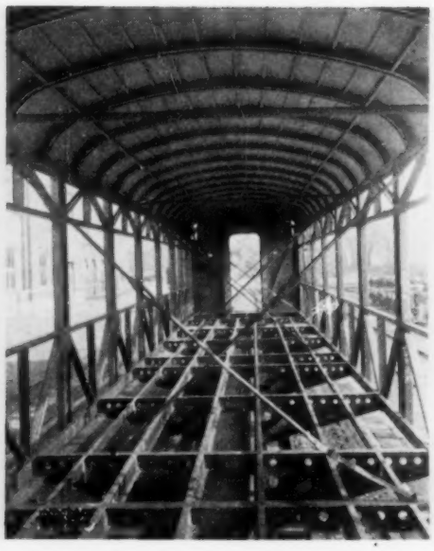


Fig. 13—Underframe and Roof Construction

Fig. 14—Completed End

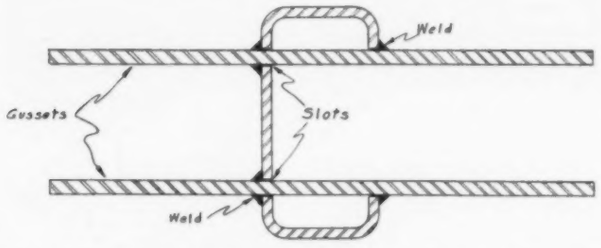



Fig. 11—Cross Section of Post or Diagonal Showing Method of Welding to Gussets

sections welded together to form a flanged channel. The top flanges of the Z's are butt-welded together by the Union Melt process as shown in Fig. 12. All cross members are fabricated from plate sheared to size and arc-welded together. Sides are joined to the underframe by arc welding. Figure 13 of the interior of the car shows the construction of the underframe.

## ROOF

The roof for this car is completely spot-welded. Figure 13 also shows the construction of the roof. The first step in the construction of the roof is to weld the stiffeners to the individual sheets. The carlines and sheets are then fitted on to a welding jig the full length of the car, and then spot-welded together into an integral unit.*

## ENDS

The ends of the car are made of stainless steel sheet spot-welded to the framing members. This spot-welding is done in sub-assembly on a stationary machine. A view of the completed end is shown in Fig. 15.

* For further details on roof see June 1938 issue of THE WELDING JOURNAL.

Figs. 15 and 16—Views of Completed Car

## COMPLETED CAR

Figures 15 and 16 show views of the completed cars.

# WELDING AS APPLIED to Fabrication of Industrial Stokers*

By F. R. MASON†

THE scope of this paper is limited to the welding which is done within the confines of our Detroit Plant in fabricating the different types of stokers which we manufacture. It has been our experience, that with the equipment and set-up we have here, we can fabricate certain parts of our stokers much cheaper by welding than by bolting, riveting or casting these parts. Welding permits of great savings in weight, layout costs and assembly time, over riveted, or bolted construction. On special heavy parts, which might be cast, but where there will be but one or two parts made, the use of structural shapes welded together permits of savings in pattern and core costs, and many pounds in weight.

At our plant the welding is done in two separate departments, that is, there is a Welding Department proper, and another small group of welders in the Assembly Department.

In the Welding Department is done all the welding required in fabricating the lower and upper housings for our pulverizers, built-up gear blanks and cranks for our mechanical drives, heavy and special steel side beams for long stokers, motor pedestals, and light and heavy bases and supports for our feeders to mount on.

The welding equipment used in this department is 2—300 amps. A.C.-D.C. welders for set-up and bench work, 2—400 amps. A.C.-D.C. machines, and 1—500 amps. A.C.-A.C. machine on production. This equipment gives us a flexibility within the department, permitting us to handle medium and heavy work without overtaxing the capacities of our machines.

The welders in the assembly department take care of the welding of ducts, large and small, hoppers of all sizes, gear housings, tanks for our hydraulic drives and flue gas scrubbers, breechings, feeder brackets for special mountings, air boxes, damper frames, fabricated girders and structural supports for chain grate stokers and flue gas scrubbers, coal agitators, retort and side bar supports for our multiple retort stokers, and other miscellaneous parts. The equipment in the Assembly Department normally consists of 2—300 amps. A.C.-D.C. machines and 1—300 amps. A.C.-D.C. machine. The work in general is of light and medium weight and when heavy work must be taken care of, the facilities of the Welding Department are drawn upon.

In the interest of clarity, a general description of the types of stokers we fabricate will be given together with the welding done in connection with them.

Our chain grate stokers, in plan, are rectangular in shape, the length and width varying to suit the operating space conditions. The moving grate surface is supported on structural cross members to which connections are welded for bolting to the all-welded side girders. The rear cross member which takes the thrust from the moving grates is a built up rigid girder, continuously and intermittently welded as the details require. The side girders are made up of a web plate, cut out for air box connections to the various zones, with top and bottom chords of either angles or plates welded to the web plate. All stiffening plates are welded to the web, as well as are any intermediate connection plates. The supports for the drive transmission are also of welded construction as the heights and other dimensions vary to suit the installation. A large welded steel hopper supplies coal to the grate surface.

Our multiple retort stokers are in general batteries of rams, connected together in a line, which deliver coal through retorts, down over a sloping, reciprocating grate surface. The retort bottoms, and in some cases the side bars which carry the grate surface, are supported on built up steel members welded to suit the detail requirements. Below and connected to these welded supports are the damper sections fitted with welded attachments and connections. The coal is supplied to the rams from a large hopper extending the entire width of the stoker. The hopper, and its supports, are built of plates and angles welded dust tight. In order to keep the coal moving freely agitators of steel parts welded together, are fitted into the hoppers.

On our underfeed stokers the grate surface, and the retorts, are carried on side beams which are generally cast, but in cases where extreme length is necessary or a set of special side beams is required, these are built of steel shapes welded together. The rams as in the case of the multiple retort stoker are fed by welded steels hoppers mounted on the ram cases. The dampers which control the draft are made of steel plates with all the necessary connections welded to them. The drives for these stokers contain many welded parts such as built-up gears, gear housings, crank shafts, pressure tight steel tanks for the hydraulic drives and chain or belt guards.

Our pulverizers, or Atritas, are in general rectangular box shaped housings, with semi-circular shaped covers, which enclose a rotor disk equipped with grinding pegs, mounted on a shaft which is supported by bearings at each end. This rotor revolves at a fast rate of speed and reduces the coal to a fine powder. Thus, it is readily appreciated that the housings must be of heavy plate, properly welded for strength and dust tightness. The close clearances required in the housings necessitate the use of spacers of such lengths that after the welds are made, the shrinkages will not draw the plates too close together. The bearings on the rotor shafts rest on pedestals made of reinforced steel construction, welded complete, and then continuously welded to the housings. The coal feeders, which supply the pulverizers, are mounted on welded steel supports which also are welded to the housings. The housings are built in seven different sizes ranging in weight from a few hundred pounds to four and one-half tons each. In cases where the feeders are not attached to the pulverizers, welded steel bases are used to mount them on. The coal in powder form is blown through steel pipes, welded into the shapes required by the installation, to the burners, where it is

* Paper to be presented at Annual Meeting, A. W. S., Detroit, Mich., Oct. 16 to 21, 1938.

† Asst. Plant Manager, Riley Stoker Corp., Detroit.

mixed with air to form a highly combustible mixture. The burners are box-shaped steel housings which are made of plates and angles welded dust tight. Many small parts in the damper controls are welded since they are generally special.

All the air ducts and breechings are of plate and angle construction, welded gas tight at all seams and connections, since they are usually under either forced or induced draft.

The tanks for our Flue Gas Scrubbers must be welded water-tight throughout. These tanks are made of steel plates, reinforced by I-beams at the bottoms, and built-up structural buckstays at the sides. These tanks are supported on structural columns, to which the base plates and connection angles are welded. The ducts which carry the gases to and from the scrubber are generally very large and are made of steel plates and angles continuously welded at all joints and seams for gas tightness.

We have also carried out some experiments to determine procedures to be used in the field for welding cast bearings and clamps to pressure parts in boilers, where they are exposed to water lancing and corrosive gases.

It is evident from the foregoing descriptions that welding is used to a very great extent in the fabrication of every type of stoker we make. The use of welding has advanced rapidly since its inception at our plant and by consultation with welding engineers, new applications for it are constantly being found, as our designs change to meet new conditions and developments in the fuel burning field.

# ARC WELDING AS INFLUENCED BY

## Shop Preparation, Tools, Jigs and Fixtures*

By M. S. EVANS†

TO PROPERLY discuss this subject, as applying to use of the welding art in railway equipment construction, one must, we believe, recognize the importance of three (3) major factors, inherent to *any* structure involving arc welding. These three (3) factors—so closely allied, as to be practically inseparable, may be defined as: (a) Production, (b) Costs and (c) Workmanship.

*Production*—Deliveries affected—customers pleased or dissatisfied.

*Welding Costs*—Labor, material, operating power—of utmost importance.

*Workmanship*—Although at times controlled by production and costs, but at the same time influential of both, certainly casts its reflection on the character of the finished product.

Consequently, careful attention to all three is essential.

The matter of *welded structure production* should probably be analyzed comparatively. To the gentleman who has grown up with the rivet, and who knows its involved problems—a difficult process is unfolded—to the welding minded individual, the matter becomes one demanding careful analysis, planning and control. To the one is presented a revolutionary development—the other sees a process, purely *evolutionary*. Experience of the one—combined with the knowledge and initiative of the other, is desirable—necessary, in fact, otherwise productive results are unsatisfactory.

Briefly, without regard for operator's fatigue, a $^1/_4$-inch horizontal lap weld can be made for $0.0281 per foot, with wire costing $0.095 per pound and with labor paid $0.75

* Paper to be presented at Annual Meeting, A. W. S., Detroit, Mich., Oct. 16 to 21, 1938.

† Plant Engineer, American Car and Foundry Co., Berwick, Pa.

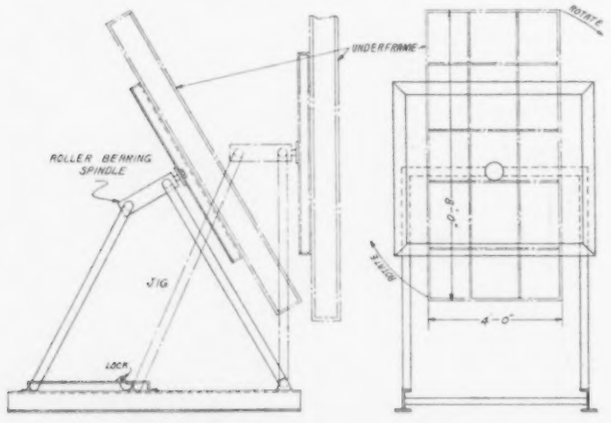



Fig. 1—Mine Car Underframe Welding Jig

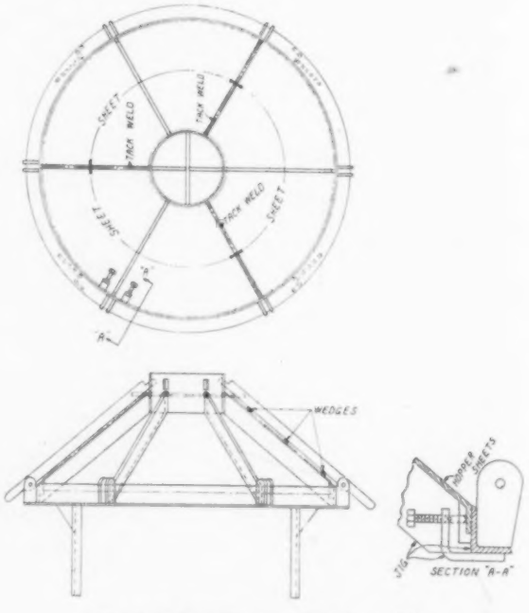



Fig. 2—3-Piece Hopper Sheet Assembly

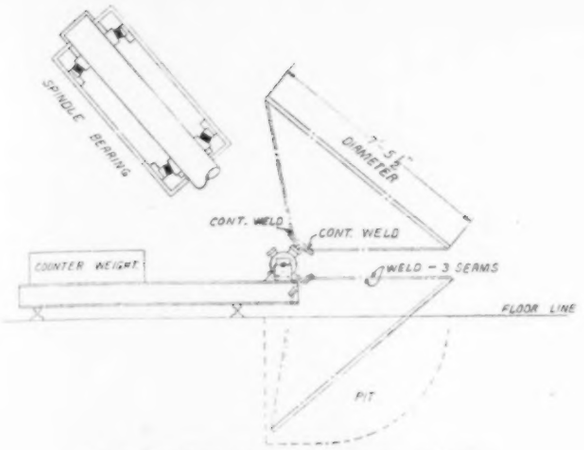



**Fig. 3—Positioner for Welding Container Hopper**

per hour.[1] However—when considered on a unit of weight basis—and we believe this to be the proper base, *such weld has cost $0.203 for each pound of metal deposited*, while of this cost, the labor involved, represents 38 per cent. Reduce the operator's efficiency, and this percentage increases. Hence, the need for careful control.

Look at it from another angle! The designer has specified a certain amount (minimum) of weld-metal, necessary to resist the imposed stresses. Weight of specified weld-metal is easily calculated. Cost estimates, labor and material, are prepared on the assumption that weld-metal will be applied as directed by drawings. Now—if more is applied than specifications direct—waste results, costs get out of line. If less is applied, strength is impaired. It is a vicious cycle.

As regards workmanship! Here we have the physical, as well as the material side of the picture to consider. Presumably the welder is a capable workman, well trained and industrious, but, is the quality and character of the item presented to him for fabrication, suitable in *all* respects? Can he be expected to produce good workmanship, and meet estimated costs, if handicapped by improperly prepared and assembled material? Will his product be satisfactory, economically or otherwise, if the tools or jigs, or other fixtures with which he must work, are inadequate for the purpose intended?

A production welder (personal) is certainly akin to a mechanical device or machine. Efficient output demands that he be in operation—*on productive work*. He cannot, without cost to his employer, be shut down—be it for lack of material—repairs or what not. Is it not logical, therefore, to state, that preparatory measures—those measures necessary to keep him in operation—are of vital importance?

The development of the arc-welding art has demonstrated need for careful consideration of many associated, and influential factors, a few of which may be listed as follows:

1. Preparation of material.
2. Fitting of associated parts at points to be welded.
3. Accessibility (to operator) of points or parts to be welded.
4. Position of work—as it must, or can, be welded.
5. Expansion, contraction and distortion stresses set-up by the welding operation.

To meet up with such conditions, we must supply adequate facilities in the way of necessary equipment—jigs, tools and fixtures. Furthermore, we must prepare material—later to be fabricated—in *consistently satisfactory* manner.

It is a generally recognized fact that arc welding *can best* be done—all factors considered—in *down-hand position*. Therefore, in designing jigs and/or fixtures one should endeavor to make such positioning possible, even though it may be necessary to incorporate in the jigs, a means for rotating same with structure assembled thereon.

Railway rolling stock—today, as in the past—is an assembled unit of "subassembled" parts. Present-day trend toward welded cars does not prohibit—rather, if proper fixtures are provided—should simplify subassemblies. Bear in mind, too, that with welded type of construction, the old time advantage of the hole, which can be reamed to fit, is not present. Consequently, consistent quality of work from subassembly jigs is essential.

The problem is not so difficult, its solution need not be unduly expensive.

Five examples of jig construction for welding use are given on sketches (shown herewith), and will be described as follows:

Figure 1, a positioning device, hand operated, designed to accommodate, for position welding, an assembled mine car underframe. (The frame has been assembled and tack-welded elsewhere than on this positioner.)

Figure 2, an assembly jig for tack welding cement container inside hopper previous to finish welding.

Figure 3, a rotating (by hand) and positioning jig for use in the assembly of inside hopper of an air-activated cement container.

Figure 4, a rather ingeneous handling device for rotating a tank (a cement container) by the operator, who must work inside the tank.

Figure 5, a fixture designed to permit the automatic arc welding of stakes to hopper car sides. This jig is a combination fitting and welding unit, so arranged that no preliminary tack welding is necessary.

In passing, one should not fail to mention the importance that machine tool manufacturers, in general, are now giving such matters. Special holders, or fixtures called "Positioners" by some, adjustable to practically any position, and designed to accommodate heavy structures, are now being marketed to the trade.

Application of weld-metal is accomplished by heat—severe heat. Heated metals expand, usually, sometimes in peculiar fashion. Jig construction must, therefore, take all such associated factors into consideration. It may be necessary to provide abnormally heavy structural supports, at certain points, if distortion is to be prevented—experience will dictate the location. Rigidity is an important characteristic, while accessibility is always essential.

However, there is another factor, an important factor. Jigs and fixtures should not be considered or intended

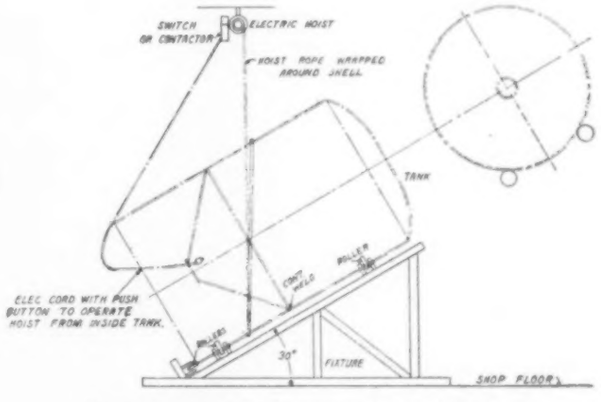



**Fig. 4—Container Tank Rotation for Inside Welding**

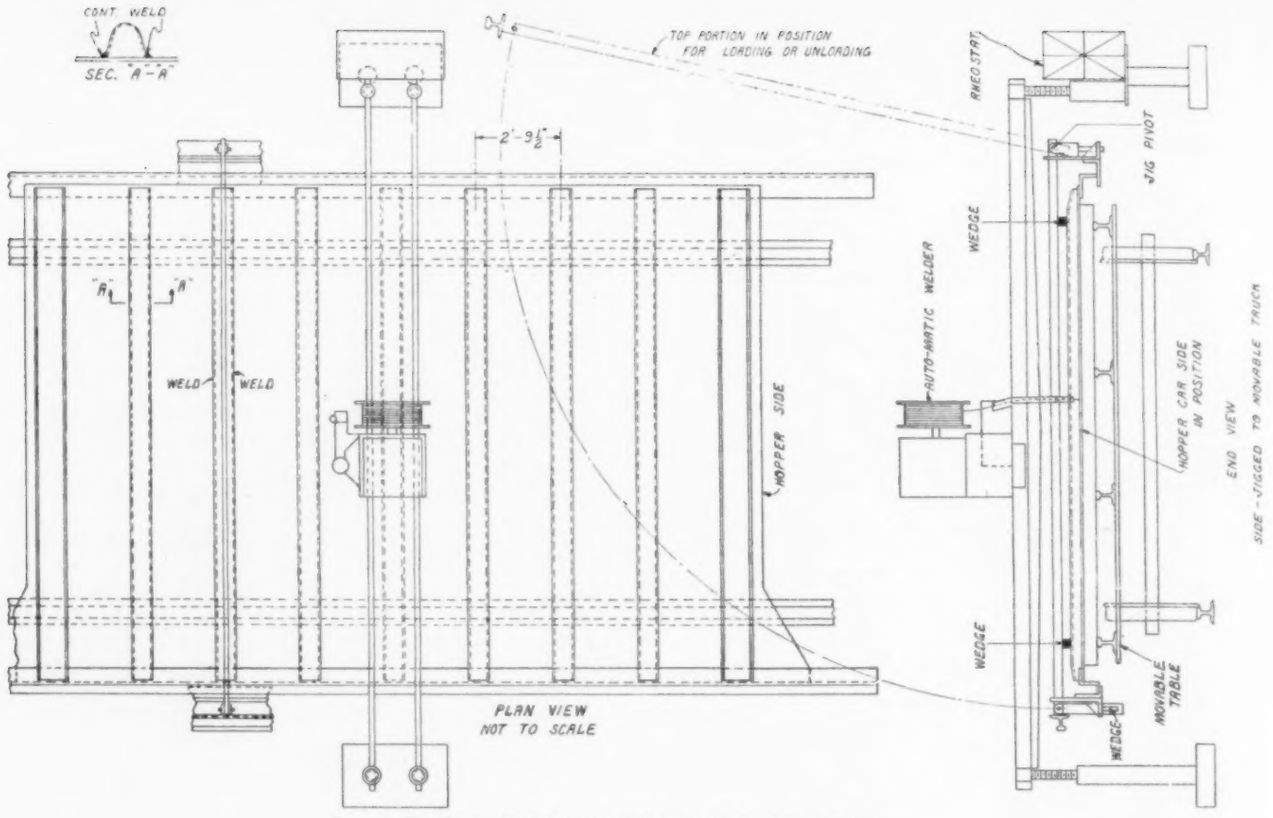



Fig. 5—Jig for Automatic Welding of Side of Hopper Car

to be a device for correcting faulty preparation. Stresses generated by welding heat cause trouble enough. Stresses imposed upon individual pieces, using pressures unwisely exerted by jigs for the purpose, are quite likely to cause difficulty elsewhere in the finished structure.

Proper preparation of materials—and we have already mentioned this—is of *vital* importance. Badly fitted joints require additional weld-metal—increased cost. We have seen, in recent weeks, on a certain Hopper Car construction, a reduction of 40 pounds of welding wire per car, from that previously used on the same car—this reduction attributable 100 per cent to elimination of bad fits at welded joints. If we accept the figures given earlier herein, as being representative of actual cost, a saving of over $8.00 per car has been returned. In reality, it is much more.

Welding of badly fitted joints imposes application of excessive heat—possible distortion enters the picture—general appearance of finished product is affected, all to say nothing of locked in stresses possibly imposed through jig action on assembly. Furthermore, shrinkage cracks, particularly when welding light to heavy members, are not unusual. Such situations need not be accepted, should not be countenanced.

Briefly summarizing—in production arc welding—costs, productive output and workmanship, are *largely* influenced by Shop Preparation of materials, Tools, Jigs and Fixtures.

Shop preparation demands careful attention to involved details and proper application of existent facilities. Quite often old methods must be revised, old ideas replaced by new. Errors, influencing weld assembly and fabrication, are usually difficult, ofttimes impossible, of rectification. Proper, and consistent quality, of prepared material eliminates this difficulty.

Jig and fixture design must be influenced by structural and physical requirements, and more particularly, by need for economical application of weld-metal, in manner prescribed, giving, at the same time, due consideration to the convenience of application of said metal by the operator.

[1] Procedure Handbook of Arc Welding, 4th Edition, page 147, Lincoln Electric Company.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# FLASH WELDING OF RAILS*

By H. C. DRAKE†

IN 1937 more than 6600 tons of 131-lb. steel rails were welded by the flash butt-welding process. The welding equipment used in the fabrication of these long rails on the Delaware & Hudson Railroad has been described in various publications.[1] This discussion will indicate some of the problems involved in the development of a satisfactory flash-welding technique for high carbon large section rails.

The rail flash-welding equipment consists of a welding car housing a specially constructed flash welder, a generating car containing two turbo-generators for supplying current to the welder and its accessories, a steam locomotive for supplying steam to the turbines, a rack car on which the rails are lined and prepared for welding, a series of flat cars on which the stress-relieving and grinding equipment is located and a series of additional open-end, gondola cars, or suitable storage racks, for holding the long rails as they come from the welder. The maximum production rate of the welder is 17 welds per hour.

* Paper to be presented at Annual Meeting, A. W. S., Detroit, Mich., Oct. 16 to 21, 1938.

† Director of Research, Sperry Products, Inc., Hoboken, N. J.

Fig. 1—Welding Equipment

Fig. 2—Storing 1500-Ft. Lengths of Rail

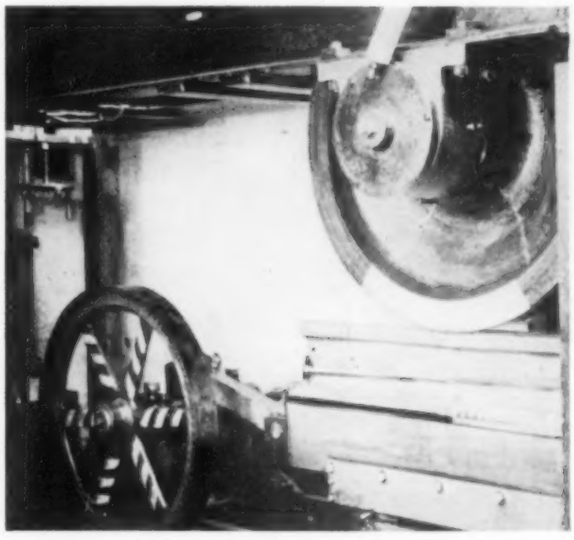


Fig. 3—Fatigue Testing Machine

The photographs of the welding equipment, Fig. 1, show the relative position of the various units. Figure 2 illustrates the manner in which the 1500-ft. lengths of rail are stored as they come from the welder.

Before initiating the design or construction of a welder, it was necessary to determine whether large section high-carbon steel rails could be successfully welded on a production basis. Welded rail in track is treated the same as continuous rail with no concern as to whether the weld is located on or between the ties, whereas the splice bars of standard rail joints are securely anchored by cut or screw spikes. In view of these facts and in absence of other criteria of joint strength, it was decided that the welded joint must be comparable to the rail steel as regards hardness, tensile strength, impact value and resistance to fatigue.

## FATIGUE TESTS

Railroad rails are subjected to severe fatigue stresses by the repeated application of heavy wheel loads. In the past year more than 20,000 transverse fissures were found in the rails of the American Railways. These fissures were fatigue failures having as their nuclei some minute shatter crack in the rail head. It was feared that the welded joints might contain some oxide or slag inclusion that would act as the nucleus for similar fatigue failures and would result in an epidemic of broken welds in service.

A fatigue test of full section welded joints was, therefore, of major importance, and a rolling wheel load machine for this purpose was installed in the laboratory.

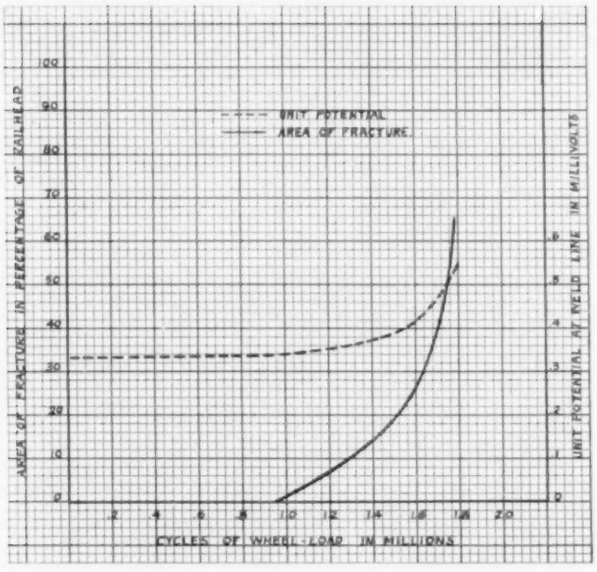

UNIT POTENTIAL
AREA OF FRACTURE
AREA OF FRACTURE IN PERCENTAGE OF RAIL HEAD
UNIT POTENTIAL AT WELD LINE IN MILLIVOLTS
CYCLES OF WHEEL LOAD IN MILLIONS

Fig. 4—Rolling Wheel Load Test Weld No. 4

This rolling load machine, Fig. 3, was developed at the University of Illinois as a means for producing fatigue failures in full section steel rails.[2] The rail is mounted in the machine as a cantilever with the weld line $1^1/_2$ inch from the support. The wheel is loaded to 65,000 lb. by means of a jack and spring at the end of the beam, and the rail is then passed back and forth under the wheel, 60 cycles per minute, by means of the motor-driven crank arm. This subjects the rail and weld not only to bending moment but also to all of the various complex stresses incident to heavy wheel loads.

Welds placed on test are inspected daily for incipient cracks by the drop-of-potential test. A current of 2000 amperes is passed through the rail and unit potential readings are taken along the rail head through the weld zone (see Fig. 4). In Fig. 5 is shown a longitudinal section through the rail head of a resistance-butt welded joint, disclosing an internal fatigue crack developed by 457,000 cycles of the 65,000 lb. wheel load. The crack was detected and its progress followed by the drop-of-potential test. This internal fatigue crack is typical of those failures developing from oxides or slag inclusions.

In the course of two and a half years' continuous operation of the rolling load machine all available types of welds were tested as well as a large number of flash welds.

The table of flash weld rolling load tests, Fig. 6, illustrates the manner in which this fatigue test was used to evaluate changes in welding or stress-relieving procedure. The first weld was given no stress relieving and the flash was only removed from the top of the rail head. Fracture started in this rail at 583,800 cycles and complete fracture occurred at 617,000. This fracture, Figs. 7 and 8, was a fatigue failure starting in the fillet under

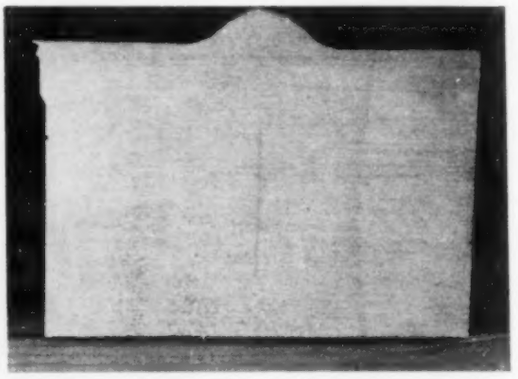


Fig. 5—Longitudinal Section Through Rail Head Disclosing an Internal Fatigue Crack

| WELD | POST TREATMENT | MILLIONS OF CYCLES 1 2 3 4 5 6 | REMARKS |
|---|---|---|---|
| 1. | NO TREATMENT | | FLASH REMOVED FROM TOP OF HEAD ONLY. |
| 2. | " | FRACTURED | |
| 3. | " | | |
| 4. | HEAT TO 1200°F. IN 7.5 MINUTES, COOL IN STILL AIR. | | HEATING NOT UNIFORM. |
| 5. | HEAT TO 1250°F. IN 8 MINUTES, OVEN COOL 30 MINUTES. | | NO SIGN OF FAILURE, TEST DISCONTINUED. |
| 6. | HEAT TO 1250° F. IN 8 MINUTES, COOL IN STILL AIR. | | " |
| 7. | COOL WELD 3 MINS. THEN HEAT TO 1250°F IN 3 MINS., HOOD COOL 20 MINS. | ← SIMPLE BEAM → | " |
| 8. | " | ← SIMPLE BEAM → | " |
| 9. | " | FRACTURED | FLASH NOT REMOVED FROM UNDER RAIL HEAD. |
| 10. | " | | HIGH SPEED WELD, TOTAL TIME 50 SECS. |

FLASH WELD ROLLING LOAD TESTS.

WHEEL LOAD 65,000 LBS., RAIL MOVEMENT 7 INS.

Fig. 6

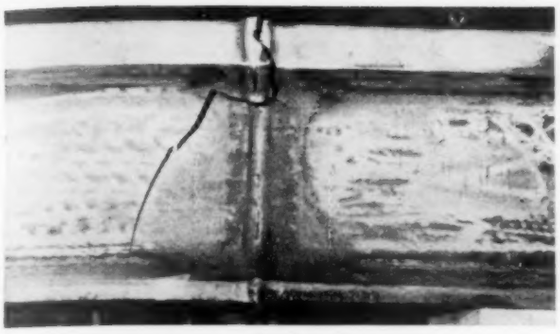


Fig. 7—Fatigue Fracture Under Head of Rail

the head of the rail. Welds Nos. 2 and 3 were given no stress relieving, but all of the flash was removed from these welds, except along the web and upper part of the base. These welds broke at about 750,000 cycles.

## STRESS RELIEVING

All of the available literature on flash welding high-carbon steel emphasizes the importance of carefully stress relieving the welded joint. In Europe, where rail steel is 0.4 carbon as compared with 0.7 carbon in this country, the flash-welded rail joints are heated in an oil-fired furnace up to 700° C. in 10 minutes. In the following 20 minutes they are gradully brought up to 800° C. and then slow-cooled by various methods for the next 60 minutes.[3] Weld production had been tentatively set at 17 joints per hour, or a weld every $3^1/_2$ minutes. It was evident that the stress-relieving technique must be a compromise, due to the high rate of weld production, methods of rail handling and other practical considerations.

As a first attempt at stress relieving, sample No. 4 was heated to 1200° F. in an interval of $7^1/_2$ minutes, and was then cooled in still air. Although the heating of this sample was not uniform, it nevertheless withstood one million cycles of the 65,000-lb. wheel load before fracture started, the final failure occurring at 1,634,400 cycles. The rate of the growth of this fracture is illustrated in Fig. 4.

Sample No. 5 was heated to 1250° F. in 8 minutes and then slow-cooled in an oven for 30 minutes. This weld was removed from the rolling load test at 3,000,300 cycles, with no sign of failure.

Sample No. 6, heated to 1250° F. in 8 minutes, and cooled in air, ran 4,720,900 cycles, and was then removed from test, with no sign of failure.

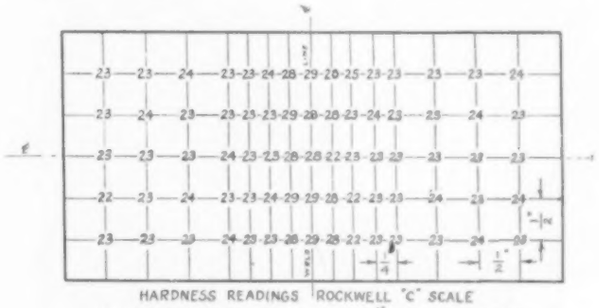
The stress-relieving procedure which was finally adopted as standard practice, consists of three phases:

1. When the weld is completed, it is immediately removed from the welder and allowed to cool in air for $3^1/_2$ minutes. This cooling allows the heat to work back from the weld line into the rail and tends to give a more uniform heat distribution around the weld zone. During this cooling cycle, the inspector checks the alignment of the top and sides of the head and the side of the rail base. A careful visual inspection of the weld is also made at this time.

2. Following the $3^1/_2$ minute cooling interval, the weld is moved into an oil-fired furnace and brought up to 1250° F. in 3 minutes, the temperature being controlled by a recording pyrometer.

3. When this heating cycle has been completed, the weld is removed from the furnace and covered by an asbestos hood which allows the rail to cool to approximately 600° F. in 20 minutes, at which time the hood is removed and the weld cools down to normal temperature in air.

The above standard stress-relieving treatment was given to samples Nos. 7 to 10, inclusive. Welds Nos. 7 and 8 were subjected to 3,000,000 cycles with the rail mounted as a cantilever and then were given an additional three million cycles with the rail mounted as a simple beam. At the completion of these tests, the welds gave no evidence of incipient cracks. Specimen No. 7 was then cut up and etched, disclosing a sound homogeneous weld.




| TENSILE TESTS 131 LB. M. M. STEEL RAIL | | | | |
|---|---|---|---|---|
| SPECIMEN | TENSILE STRENGTH LBS. PER SQ. IN. | ELONGATION LBS. PER SQ. IN. | % ELONG. | % RED. AREA |
| UNWELDED | 138,100 | 73,600 | 14 | 21 |
| WELDED | 139,700 | 79,200 | 9.5 | 18.5 |

| IMPACT TESTS 131 LB. M.M. STEEL RAIL | | |
|---|---|---|
| TYPE | SPECIMEN | IMPACT VALUE FT. LBS. |
| CHARPY | UNWELDED | 2.5 |
| " | WELDED | 3.9 |
| IZOD | UNWELDED | 1.8 |
| " | WELDED | 2.5 |

| DROP TESTS 131LB. CARBON STEEL RAIL | | |
|---|---|---|
| NO. OF SAMPLES | HEIGHT OF DROP | BLOWS TO FRACTURE |
| 3 | 22' | 1 |
| 9 | " | 2 |
| 5 | " | 3 |
| TOTAL 17 | | |

Fig. 9—Physical Properties of Welds

The ridge of flash, or upset metal, around the weld is extremely hard and its removal involves time and expense. A series of rolling load tests were made to determine how much of the flash should be removed. Sample No. 9 was placed on test without removing the flash from under the rail head. At 1,336,700 cycles this weld

Fig. 8—Fatigue Fracture Started in the Fillet Under Head of Rail

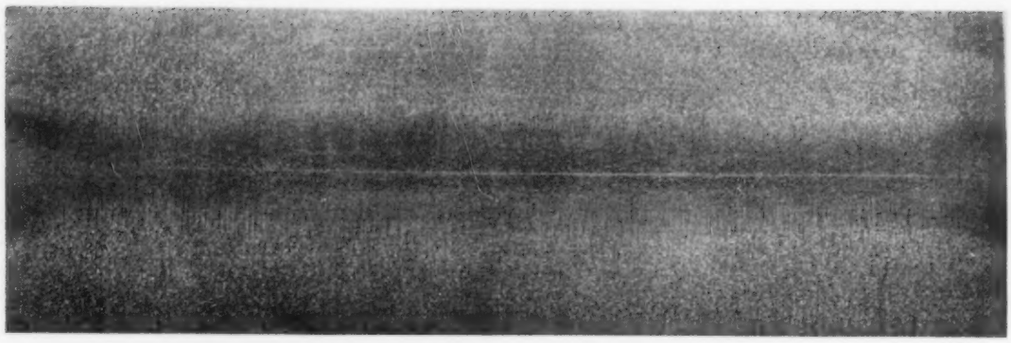


Fig. 10—Central Longitudinal Section Through the Weld—Etchant Hydrochloric Acid

developed a small fatigue crack starting at fillet under the head. As the result of this series of tests, specifications called for the removal of all of the flash except on the web and the upper side of the base. The flash under the rail base is removed immediately after welding, by means of a shear attached to the platen of the welder. The flash around the head and outer edges of the base is removed by grinders designed for the purpose.

Various phases of the welding cycle were examined to determine their bearing on weld quality. Sample No. 10, Fig. 6, shows the result of insufficient welding time. This specimen was welded in 50 seconds; it failed at 738,800 cycles. Slow flashing, or a momentary interruption of the flashing immediately preceding push up, also results

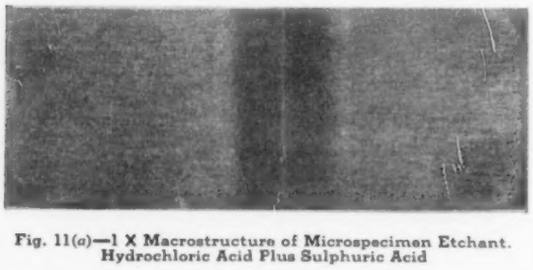


Fig. 11(*a*)—1 X Macrostructure of Microspecimen Etchant. Hydrochloric Acid Plus Sulphuric Acid

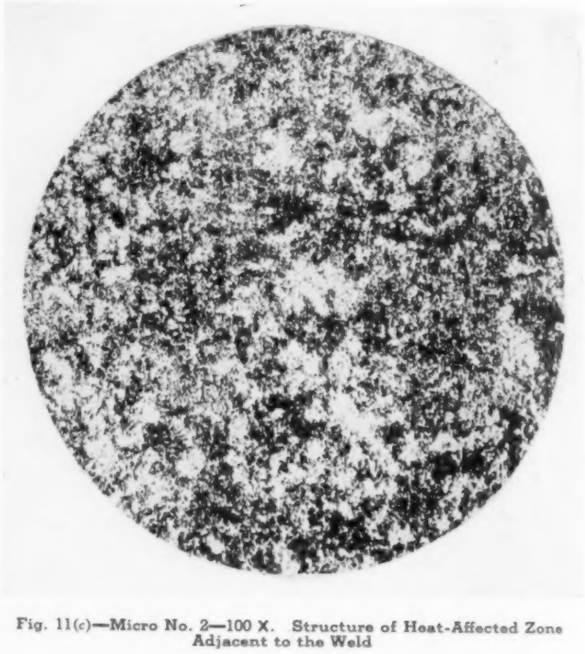


Fig. 11(*c*)—Micro No. 2—100 X. Structure of Heat-Affected Zone Adjacent to the Weld

Fig. 11(*b*)—Micro No. 1—100 X. Structure of As-Rolled Steel

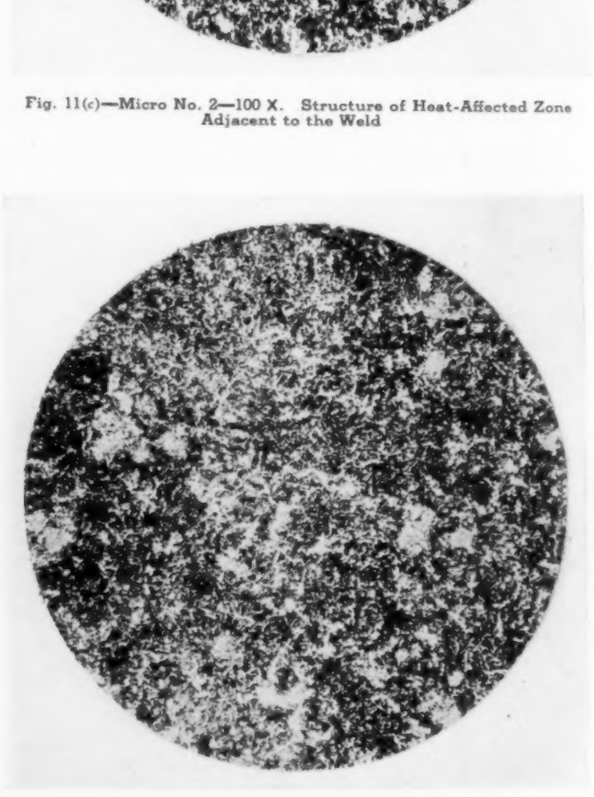


Fig. 11(*d*)—Micro No. 3—100 X. Structure at the Weld Line

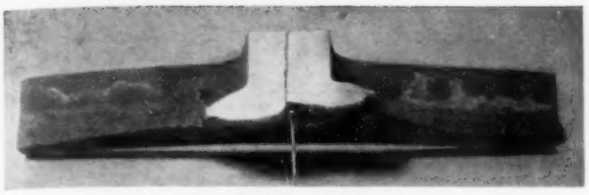


Fig. 12—Section Showing Pipe in Rail

in a weld of inferior quality. This has been explained by the theory that in flash welding the atmosphere is excluded by the gas pressure due to the rapid flashing and thus no oxide can form unless the flashing is interrupted just prior to push up.[4] The final welding cycle consisted of a 90-second preheating, accomplished by intermittent flashing of the rail ends, followed by 15 seconds of rapid flashing and a quick push up, the final push up pressure being 10,000 lb. per sq. in.

## PHYSICAL PROPERTIES

Data on the physical properties of the welds is given in Fig. 9. Hardness values taken at a section $^1/_8$ inch below the surface of the head show a maximum increase of about 7 points Rockwell at the narrow welded zone. Readings taken on a longitudinal section show a corresponding increase in hardness at the heat-affected zone in the lower section of the rail head.

Comparative impact tests of the weld-metal and as-rolled metal show a slightly higher impact value for the weld.

Tension tests on the weld-metal and the as-rolled metal give practically the same tensile strength and yield point. There is, however, a decrease in per cent elongation and reduction of area in the weld-metal.

The only physical test in the specifications for open-hearth steel rails at the mill is the drop test.[5] In the case of 130-lb. rail, the test-piece is mounted on supports spaced 4 feet apart. A 2000-lb. tup is dropped 22 feet., the anvil of the tup striking the rail midway between the supports. If the rail breaks, it was a poor rail. If it withstands the first blow, it is a good rail. Standard drop tests have been made on 17 welded joints in 131-lb. carbon steel rail, and only three of these joints broke on the first blow.

A longitudinal section through the weld, Fig. 10, shows the weld line and the heat-affected zone. The peculiar dark appearance of the heat-affected zone is due to the displacement of the steel fibers by the pushup pressure. This presents the ends of the fibers to the etchant and results in a deeper etch.

Microphotographs, Fig. 11, were taken of the as-rolled metal, the heat-affected zone and the weld line. They show the gradual change from the normal as-rolled structure to the fine grain structure of the weld.

In the early operation of the welder, current was introduced into the rail ends by means of copper contacts at the head and base. It was found that bits of loose flash caused high resistance contact on the rail base with resulting small burns. This difficulty was eliminated by insulating the rail base and introducing all of the welding current into the rail ends through the head.

In flash welding, as in other types of welding, the quality of the weld is dependent upon the quality of the parent metal. In the last winter a flash weld failed in track at $-20°$ F. It was found that one of the rails composing the welded joint was a piped *A* rail. On the final push up the faces of the pipe had separated, thus, producing a transverse crack approximately $^1/_2$ inch wide and 2 inches long in the web of the rail. In Fig. 12 is shown a section through the web of the rail, disclosing the pipe and the manner in which its faces were flared out in the weld line. In the future all *A* rails will be tested for pipes before flash welding.

Test data taken on a large number of samples indicates that high quality welds are produced by the welding technique described. To insure duplication of the correct welding cycle, the human element has been practically eliminated by making the welding operation automatic. As additional safeguards to weld quality, permanent records are made of the welding voltage, wattage, platen movement and the stress-relieving temperature for every weld fabricated. These records provide the customer with a permanent history of every weld.

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# QUALITY AND EFFICIENCY IN Oxygen Cutting*

By G. M. DEMING†

## A Discussion Concerning Superior Cutting Technique as Related to Machine Cutting

### FUNDAMENTAL REQUIREMENTS

EVEN a novice may readily develop enough skill to make some acceptable cuts when an oxyacetylene cutting torch is mechanically guided by a motor-driven device. The optimum performance with the minimum cost for labor and gases, however, can only be realized when both the fundamental principles and the cardinal details of the art of machine cutting are fully appreciated.

One of the basic requirements is that merely moderately good equipment is not to be tolerated. Progress in this field has been so rapid that equipment lagging modern design standards, is usually both uneconomical and of decidedly inferior performance. The equipment must be of the very best. This means that every item including machine, pressure regulators, hose, torch and tips must measure up to certain definite standards.

A second basic consideration is that all equipment should be guarded against abuse, and intelligently maintained in efficient working condition. A great deal of poor quality work may be traced to careless or ignorant abuse of machines, torches and cutting tips. Serious impairment or derangement of apparatus is far easier to prevent than to cure. Ceaseless vigilance to prevent abuse of apparatus will pay ample returns in the quality and the economy of the work executed.

### SELECTION AND CARE OF EQUIPMENT

For the novice it is important to understand that the technology of oxygen cutting is a highly developed one, and that a proper analysis of any given situation is often so complex that merely superficial appraisal is seldom satisfactory. For instance, there are cutting machines available which are specifically adapted to many different types of work. A common fault is to expect or even to demand too wide a range of performance for a given cutting machine. It is always best, therefore, to critically examine the superior performance of a machine adapted for some specific production job as compared with the performance of any contemplated machine of wider range of performance.

In the selection of a cutting machine, the following features are among the most important.

1. The machine should be adapted for the class of work contemplated, with a reasonable insistence upon flexibility so far as other classes of work are concerned.
2. The movements of the machine should be smooth; i.e., the translation of the torch should be steady and free from any tendency toward jerky movements within the full speed range of the machine.
3. The machine and particularly the torch bearing portion of the machine should experience no perceptible vibration during the operation of the machine, if a cut of the most precise type of workmanship is desired.
4. The torch movements should be precise and reproducible well within the limits of the precision of cutting desired of the machine. That is, there should be no "lost motion" or readily distorted movements of the torch as, for example, might come about if some guide-rail or rack is unduly exposed to the possibility of injury.
5. The torch mounting should be sufficiently rigid to obviate the possibility of disturbing the position of the torch during the cutting operation as the result of accidental but not unreasonably severe disturbance of the torch or hose line.
6. Moving and sliding parts and particularly gears and racks which are in operation during the cutting process should be well isolated or sufficiently protected from the possibility of flying sparks or slag.
7. The machine should usually be capable of a wide range of operating speeds and should preferably be equipped with some means of roughly indicating the rate of traverse of the cutting torch over the work material.
8. If the machine is of the so-called portable type it should be provided with suitable handles or grips and properly balanced with this end in view.
9. There should be as few protruding members or projecting appurtenances as possible so as to minimize the possibilities of the operator disturbing the motion of the machine while it is in operation.
10. The electrical and mechanical features of the machine should be proved to be dependable, and of reasonable life under normal operating conditions.

A machine torch must be specifically adapted to the machine with which it is to be used in that it must be of the correct length, be fitted with a rack, if such is required, or with other special appurtenances. It is also necessary that the torch be adapted for the type of gas contemplated as a fuel gas. In selecting a torch for machine cutting, care should be exercised to ensure that a torch is obtained in which the construction is uniformly rugged. Usually the barrel should be strong enough to be dent-proof under rough usage. All wearing parts, such as racks and tip-seating surfaces should be of durable

* Paper to be presented at Annual Meeting, A. W. S., Detroit, Mich., Oct. 16 to 21, 1938. This paper is to a considerable extent a condensation of material presented in the Chapter on "Oxygen Cutting" in the new AMERICAN WELDING SOCIETY HANDBOOK.

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materials. The valves should be such as to be readily maintained in good condition with minimum trouble and expense. It should be understood, however, that a true appraisal of the quality of a needle valve or an oxygen cutting valve must rest largely on experience. These important elements of a torch should not be judged superficially. Two valves of the same general type may be utterly different in performance because of vastly different standards of manufacturing and design with regard to small but very important details.

In the case of heavy cutting, even more important than the matter of substantial torch construction and dependable valves, is the question of free gas passages. Excessively small oxygen passages not only demand the use of much higher oxygen pressures, but in many cases give rise to very objectionable variations in the gas-ratio of the preheating flames whenever the cutting valve is opened or closed.

The diameter of the smallest restriction in the cutting oxygen passages of a torch should be at least 20% larger than the cutting orifice of the largest cutting tip used with the torch. If there is a marked enlargement between that restriction and the point at which the oxygen enters the tip, it may be preferable for the restriction to be as much as 50% larger than the cutting orifice. Thus, if the torch is to be used with a tip which has a No. 30 drill size cutting orifice (diameter of 0.128 inches) and if there is a marked enlargement on the order of $^1/_4$ inch or greater between the cutting valve and the tip, make sure that the diameter of all other passages, including that of the opening through the cutting valve, is at least $^3/_{16}$ inches.

If it is desired to avoid the slight inconvenience of opening the oxygen cutting valve when adjusting the preheating flames, and an appreciable, although a very small deviation in flame quality accompanying manipulations of the cutting valve, a "3-hose" torch may be employed. In this torch the oxygen supply for the cutting jet is entirely independent from the oxygen supply for the preheating flames.

The "3-hose" torch has two more important applications, however. One of these is that of multiple torch operation, and the other is that of affording independent metering of the cutting oxygen and of the fuel gases when such is required for the purpose of cutting tests or special cost analyses.

The intelligent choice of a torch will do much to ensure satisfactory torch performance, but even with the best of torch designs it is essential that in actual use every effort be made to protect the tip-seating surfaces, the hose gland seats, threaded parts, the teeth of the rack, if any, and the valve stems and seats. Particular care should be exercised in handling torches when they are not mounted on a machine. Such practices as dragging a torch by means of the hose lines should be condemned.

Successful machine cutting operations are only possible when proper care is exercised in the selection and maintenance of cutting tips. An important consideration with respect to the selection of cutting tips relates to the material of which the tip is constructed. Only tips of commercially pure copper are fully practicable for other than occasional service.

The discriminating user of cutting tips will not only insist on tips made of pure copper, but he will also bar any cutting tips that are not characterized by accurately aligned drillings with smooth walls. Where there is an enlarged approach passage to the cutting orifice, it is important that such a passage provides a smooth entry for the oxygen into the cutting orifice. This does not mean that the approach drilling or "relief hole" should necessarily be absolutely concentric with the cutting orifice, but it does mean that the shoulder created by the intersection of the cutting orifice with the bottom of the relief hole should be complete, and that in no case should it be difficult to insert a cleaning drill entirely through both cutting orifice and relief passage.

Tips are sometimes furnished to the trade which have excessive diameters at the discharge ends of the tips. It is particularly important in the case of smaller sizes of tips with low preheat intensities that the terminal diameter of the tip be not excessive. Otherwise, it proves difficult to critically observe the condition of the preheating flames during the progress of the cut. On the other hand, the terminal diameter of the tip should not be so small that the preheating orifices are too close to the circumference of the tip or are pinched together too much. If either of these conditions is found the life of the tip under the influence of the preheat is liable to be deficient.

Generally speaking, the gas economy of the tip is not influenced by the number of preheating flames per se. With the very smallest tips of extremely limited heat intensity, however, it is sometimes impracticable for manufacturing and maintenance reasons to use excessively small preheating orifices. Accordingly, two flame tips are sometimes more economical and are more desirable from the viewpoints of design and maintenance. Such tips, of course, are only practical in the case of straight line cutting. The four (or more) flame tips are, however, suitable for shape cutting.

If the preheating flames are too near the cutting orifices, the flames are likely to be drawn away when the cutting jet is turned on. This is particularly important where heavy discharges of oxygen are involved with the larger cutting tips. Not only should the preheating flames not be too close to the cutting jet but as much flame stability as possible should be obtained through careful design of the preheating orifices. That is, the flames should be balanced and capable of a considerable range of adjustment as to size or intensity.

There are many hidden defects possible, so that in purchasing tips one should first of all be assured that the tip has been most rigorously inspected at the factory and secondly, that the tip is capable of performing in a satisfactory manner, under actual working conditions.

The susceptibility of a tip to flash-back should carefully be observed when the tip is in use. This aspect of gaging cutting tips, as well as that of minor defects of the cutting orifice, can only be critically evaluated if the operator is experienced and most careful not to ascribe to the tip either defects in the steel being cut or faulty operating procedures. In general, it is important that the steel being cut be of more than one heat, and that all of the details governing correct procedure should be observed before condemning a given tip.

The optimum performance of the cutting tip can only be realized when its use is intelligently supervised and the tip is subjected to adequate maintenance. In this respect it is particularly important that precautions be taken to protect the seating surfaces of the tip against damage by dropping the tip or scratching the seating surfaces with hard or sharp articles. It is also important to keep the tips clean and prevent foreign material from becoming lodged in the small orifices. To accomplish both of these ends it is advisable to keep the tips in appropriate receptacles provided for the purpose.

One should also make sure that the seating surfaces of the torch head are very clean before assembling the tip. If upon lighting a tip it is found that the acetylene burns around the tip nut, and consequently that there is a leak across the seating surface of the tip, it is important that the tip be removed and the seating surfaces scrutinized

before attempting to stop the leak by further tightening the tip nut.

Cutting tips are frequently damaged by allowing the end of the tip to rub across the upper surface of the steel plate while the torch is mechanically traversing the plate. Accordingly, great care should be exercised to ensure that at all times there is sufficient clearance between the end of the tip and the surface of the work.

When not skillfully accomplished, the cleaning of the cutting orifices may actually do more harm than good. Because the terminal portion of the cutting orifice is often contracted as the result of heat and some tightly adhering particles of slag, it is desirable to insert the cleaning drill into the rear of the tip, when this is practicable, rather than into the discharge end. The cleaning drill should be very carefully rotated and never forced. Only the cleaning drills recommended by the manufacturer of the tip should be employed.

It is most important that pressure regulators be correct as to type. By this, such considerations as delivery-pressure range, flow range, gas employed and inlet pressure limitations are signified. Where high standards are entertained as objectives in machine cutting, it is folly to employ almost any regulator merely because it is possible to draw gas from the regulator at the working pressure desired. So far as adequate pressure regulation is concerned, a good two-stage regulator is very frequently essential.

## SELECTION OF GAS

One of the most essential requirements for efficient cutting operations is that the oxygen be of highest purity. The pernicious influence of what might otherwise be regarded as trivial amounts of impurities is illustrated by Fig. 1. It will be observed that the decrease of oxygen purity from 99.5 to 98.5% will on the average necessitate an increase in oxygen consumption of about 25%.

Although acetylene is the most widely used fuel gas for oxygen cutting torches, under some exceptional circumstances other gases may compete on an economical basis. One is not in a position to choose the proper fuel gas if he merely has a knowledge of the B. t. u. content of the various gases and the relative cost. This is clearly illustrated by the studies of preheating or "starting time" covered by Fig. 2, for it has been proved that a preheat intensity that is sufficient to rapidly start the cut is adequate for rapid and highly economical cutting operations. Figure 2 illustrates the variation in preheating time characteristic of typical fuel gases and various oxygen fuel-gas mixtures. The preeminent position of acetylene as a fuel gas is indicated by the exceptionally low starting times and low rates of gas consumption involved for the two acetylene curves. It will be observed that the minimum starting time with acetylene requires an oxyacetylene ratio of about $1^3/_4$ to 1. In the case of propane, which requires very little fuel gas to attain comparable minimum starting times, the oxygen-propane ratio is about $4^1/_2$ to 1. Accordingly, the use of propane as a fuel gas requires the consumption of very much more oxygen for the heating flames than does acetylene, when the same starting times are involved.

**Table 1—Relative Volumes of Fuel Gases to Produce Equivalent Rates of Heating**

| | Volume of Fuel Gas Cu. Ft. per Hr. | Volume of Oxygen Cu. Ft. per Hr. |
|---|---|---|
| Acetylene | 1.0 | 1.7 |
| City Gas | 7.5 | 5.6 |
| Natural Gas | 2.8 | 5.6 |
| Propane | 1.0 | 4.5 |

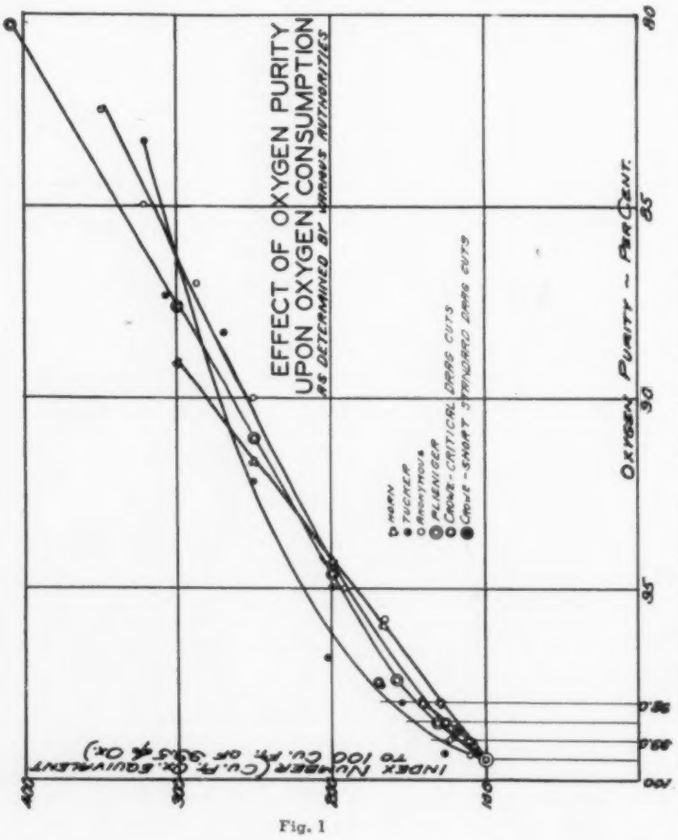

EFFECT OF OXYGEN PURITY UPON OXYGEN CONSUMPTION
AS DETERMINED BY VARIOUS AUTHORITIES
OXYGEN PURITY — PER CENT.
INDEX NUMBER (Cu. Ft. Ox. EQUIVALENT TO 100 Cu. Ft. OF 99.5% Ox.)
HORN
TUCKER
ANONYMOUS
PLUENGER
CROUT - CRITICAL DATA CUTS
CROUT - SHORT STANDARD DATA CUTS

Fig. 1

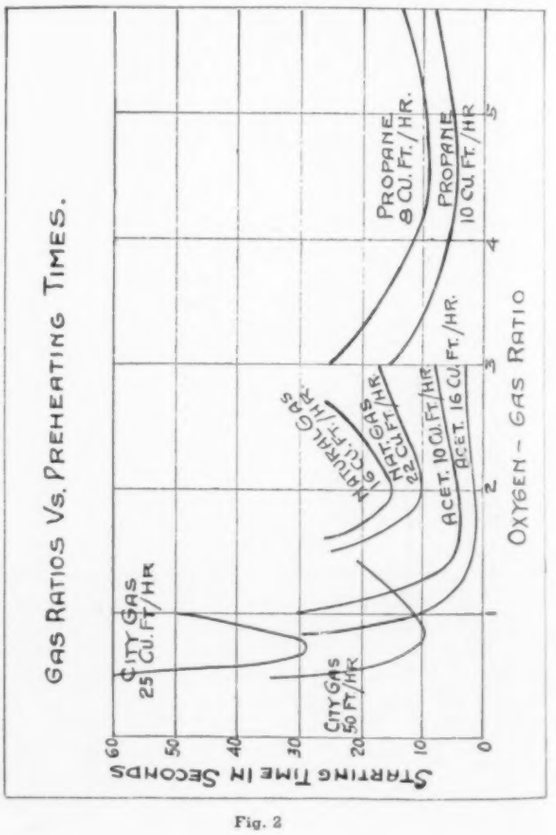

GAS RATIOS VS. PREHEATING TIMES.
STARTING TIME IN SECONDS
OXYGEN - GAS RATIO
PROPANE 8 CU. FT./HR.
PROPANE 10 CU. FT./HR.
ACET. 10 CU. FT./HR.
ACET. 16 CU. FT./HR.
NATURAL GAS 22 CU. FT./HR.
CITY GAS 25 CU. FT./HR.
CITY GAS 50 FT./HR.

Fig. 2

Table 1 indicates the fuel gas and oxygen volumes required to do the same work of preheating as one volume of acetylene and $1^3/_4$ volumes of oxygen.

The most striking feature of the above table is the relatively large volume of oxygen required to burn the saturated hydrocarbons, such as city gas, natural gas and propane. Despite the low price at which these low-temperature gases are available, the cost of this extra oxygen weighs heavily in favor of acetylene as the most economical fuel gas.

## PERSONNEL

Although a beginner may readily execute cuts of fair quality, high-quality workmanship and economy of operations are dependent to an unusual degree upon skill and intelligence.

Because of the many complex variables involved and the fact that these have not been fully rationalized even at this date, it is utterly impossible to lay down highly detailed operating specifications. Such tables of cutting procedure as are furnished to the operator must necessarily be looked upon as cutting guides rather than cutting specifications. The operator must be capable of employing such outlined instructions to develop the most satisfactory procedure for the particular job in question. This means that at times trial-and-error methods must be invoked, but unless the operator is very methodical he is liable to be tempted to experiment excessively, or else to reach premature conclusions. In the former case a great deal of time, gas and steel may be wasted. In the latter case many cuts may be ruined, expensive pieces of steel wasted, and the very best results which are possible with the process may not be realized. As an example of what is customary where the operator is not carefully chosen, and where the supervision is not of the very best, it was found during one series of inquiries that the oxygen consumption for cutting 6-inch material varied by over 150% in different shops.

The operator and the supervisor must, above all, have a sense of proportion. There are many instances in which excessive emphasis has been placed upon either quality or dependability of cutting to the detriment of the element of economical cutting. On the other hand, there are times when the cost item has been so magnified that ill-advised conclusions are reached on the basis of insufficient information or tests. In other words, generalizations are sometimes reached that are entirely applicable for the particular type of steel or the particular cutting conditions involved, but which are independable or even totally inapplicable for slightly different cutting conditions.

Consequently, the operator should be restrained from aimless and premature experimentation, but encouraged to constantly but cautiously investigate new cutting conditions. He should also be not only sufficiently critical but in addition well informed as to acceptable means of experimentation.

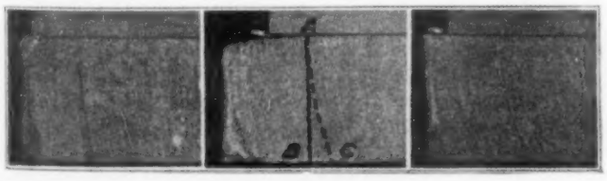


Fig. 3—Specimens of One-Inch Cuts. Left: Drag 0.11 Inch. Lower Corner Completely Severed. Center: Drag 0.20 Inch. Corner Completely Severed. Right: Drag 0.22 Inch. Lower Corner Not Completely Severed. (Fracture in Lower Left-Hand Corner Not Clearly Revealed by Photograph.)

## INTER-RELATIONSHIP OF QUALITY AND EFFICIENCY

The most important independent variables are as follows:

1. Size of the cutting orifice
2. Oxygen operating pressure
3. Speed of cutting
4. Thickness of the material being cut
5. Quality of the material
6. Purity of the oxygen
7. Intensity of the preheat
8. Angle of incidence of the cutting stream to the upper edge
9. Smoothness of cutting orifice
10. Cleanliness of the end of the tip

For any given cut each of these variables should be so evaluated that a satisfactory quality of cut may be achieved at a minimum expense. A commercially satisfactory quality of cut is chiefly defined by:

1. A sufficiently short drag. That is the line markings on the face of the cut (Fig. 3) should approach the condition of being straight up-and-down rather than dragging back so far that a large (lower) corner is not cut and must be broken off.
2. Sufficiently smooth sides of cut, i.e., not grooved, fluted or ragged.
3. Satisfactory slag condition. For most production work there should be no firmly adhering slag that involves an appreciable expenditure of labor for its removal.
4. The upper edges of the cut should be sufficiently sharp for the requirements of the particular job.

The most basic of these requirements is that of a sufficiently short drag. Let a series of cuts be made with a given tip at a constant speed and with varying oxygen operating pressures. Next, let a line, such as $AB$ Fig. 3, be inscribed normal to the upper edge of each cut and on one face of the cut. If the particular drag-line which originates at $A$ be followed downward to its lower terminus, $C$, then the distance $BC$ may be recorded as the length of drag involved for that particular cut. If for any given tip the oxygen consumption necessary to give rise to each particular length of drag (the speed being constant) is plotted against this drag, a curve somewhat similar to that of Fig. 4 is obtained. Figure 4 is typical in that:

1. The increase of the oxygen consumption becomes greater (i.e., the pressure must be increasingly augmented) as the length of drag decreases, and for very short drags a slight decrease in the drag length can be procured only at the expense of a very greatly increased oxygen consumption. This fact is of fundamental importance when considering the question of cutting economy.
2. Except for the lower cutting speeds, a minimum length of drag is characteristic of a given speed and tip which may not be decreased regardless of the operating pressure (or the oxygen consumption).
3. An increased drag may result if an attempt is made to obtain a drag shorter than the minimum by increasing the operating pressure beyond that at which the minimum drag is obtained.

If the drag is too short the cutting operation becomes expensive as a result of the greatly increased oxygen consumption. If the drag is too long an uncut final corner may be the result. An uncut corner is frequently undesirable because: (1) The appearance of a broken corner is of importance, or (2) The length of drag necessarily involved in the case of uncut corners implies that the edges of the cut will not be exactly square with the face of the plate being cut when circular or irregular shape cutting is involved, or (3) The non-uniform quality of the material is such that considerable reserve oxygen must be available beyond what is just sufficient to accomplish complete penetration of the plate when everything is favorable.

Obviously, an effort should be made to select some definite length of drag as standard for any given operation. Merely to ignore the matter is to run the risk of wasting much oxygen as well as of obtaining poorer quality cuts.

Some plants select the zero drag, or nearly zero drag, as standard. For shape cutting where sharp corners, or curves of short radii are involved, there is frequently justification for selecting so short a drag, but it should be understood that when such a drag is chosen the speed of cutting is necessarily reduced and the oxygen consumption increased so that the operation is decidedly more expensive than if a longer drag is employed.

Cutting studies such as those which form the basis of the data of Fig. 5, will enable the supervisor to determine whether zero drags are sufficiently desirable as to be economically justified. Referring to Fig. 5 it will be seen that if a No. 45 (drill size) orifice is employed a zero drag may be realized when cutting the particular steel if the cutting oxygen consumption is about 300 cu. ft. per hour and the speed about 4 inches per min. If, however, a drag of $^5/_{16}$ inch is tolerated, then with the same orifice and the same oxygen consumption a speed of $6^1/_4$ inches per min. instead of 4 inches per min. (a 56% increase in production rate) is possible. From another angle if it be assumed that for the zero drag cut a No. 41 orifice and a $6^1/_4$ inches per min. speed are employed, then the oxygen requirement as indicated by Fig. 4 will be about 365 cu. ft. per hour. On the other hand, if a $^5/_{16}$-inch drag is selected, then at the same speed the cut may be made with the next smaller size of cutting tip (the No. 45 orifice) and the oxygen requirement will be reduced to 300 cu. ft. per hour.

It is obvious that in the interest of economy the drag should be as long as possible. If it is actually permissible, so far as the requirements for the finished cut are concerned, to employ much longer than zero drag it is quite likely that a "standard" drag or one which is as long as possible without leaving an uncut final corner, will be the maximum permissible drag. The middle cut of Fig. 3 is characterized by such a drag. Where the drag is shorter the oxygen stream is able to complete the oxidation of the lower final corner even though the length of drag involved may be somewhat greater than the diameter of the cutting jet.

In full recognition of the possibility of both shorter and longer drags being more suitable in special instances, the term "standard" drag has been employed both as a matter of convenience and because it is a standard which has been found to be quite generally satisfactory. It turns out that in the majority of cases the "standard" drag as here defined is also suitable for circular cutting and the cutting of irregular shapes. This "standard" drag may be expressed as follows:

**Table 2**

| Thickness of Material in In. | Approx. Length of "Standard" Drag* in In. |
|---|---|
| $^1/_2$ | $^3/_{32}$ |
| 1 | $^{13}/_{64}$ |
| 2 | $^7/_{32}$ |
| 2 to 6 | $^1/_4$ |

* Based upon the assumption that the "final" edge of the work material is exactly perpendicular to the line of torch traverse.

At times it is preferable to standardize upon the degree of off-square condition for a cut of known radius or upon the size of an uncut final corner, rather than upon the length of the drag. At any event, the shop which does not have some criterion of cut quality, either directly or indirectly related to length of drag, even if the standard is only an approximate one, will almost cer-

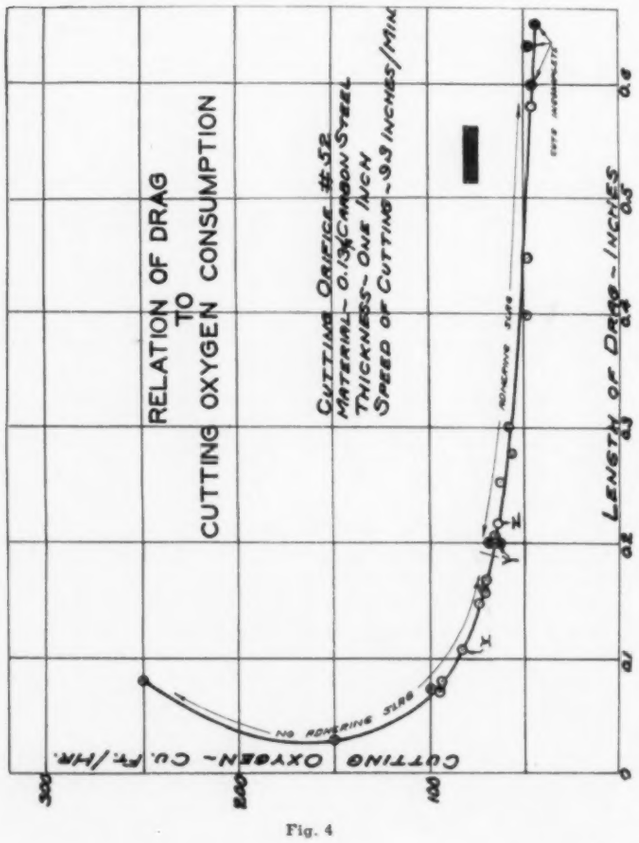



Fig. 4

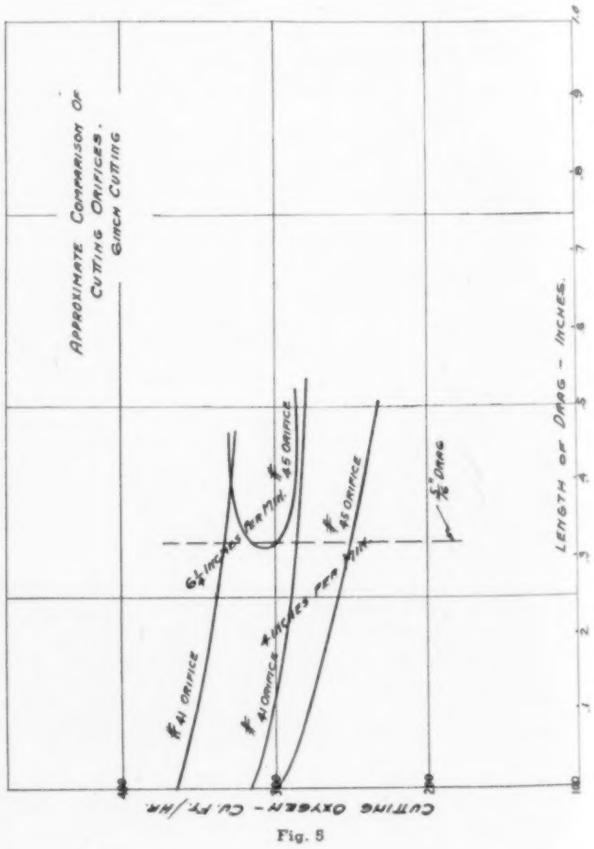



Fig. 5

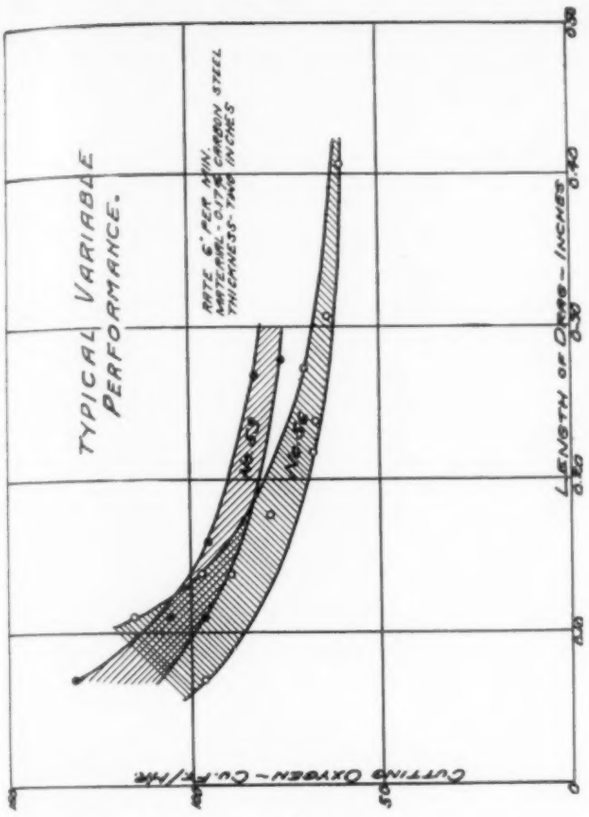

TYPICAL VARIABLE PERFORMANCE.
RATE 6" PER MIN. MATERIAL CUT CARBON STEEL THICKNESS-TWO INCHES
No. 53
No. 55
LENGTH OF DRAG - INCHES
CUTTING OXYGEN - CU. FT./HR.

Fig. 6

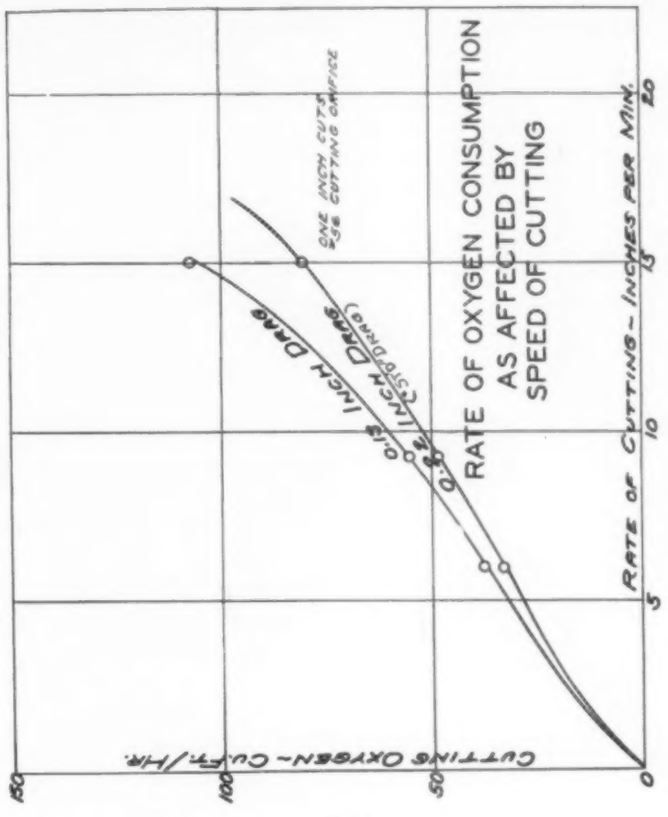

ONE INCH CUT 4 CUTTING ORIFICE
RATE OF OXYGEN CONSUMPTION AS AFFECTED BY SPEED OF CUTTING
LENGTH OF DRAG (STRAIGHT LINE)
RATE OF CUTTING - INCHES PER MIN.
CUTTING OXYGEN - CU. FT./HR.

Fig. 7

tainly experience excessive costs for its cutting operations.

## BASIC CUTTING PROCEDURE

Because of extreme variations in such things as the quality of the steel, the cleanliness of the tip, and the skill of the operator, as well as in the acceptable standards of performance, it is not possible to establish a universally dependable table of cutting pressures, tip sizes and speeds. Cutting tables must not be looked upon as cutting "specifications" but rather as approximate cutting "guides" which fit certain average conditions sufficiently close so that trial cuts may be made with a fair presumption of success. Following the inspection of the trial cut, more practical working conditions for the particular job may be evolved by carefully and appropriately varying the speed of cutting, the tip size and the operating pressure.

After an operator has acquired sufficient experience with the particular thickness and quality of the steel involved, he may depart rather widely from the conditions specified, particularly in the direction of lower operating pressures and higher speeds, provided he does so cautiously and with due recognition that one or two successful cuts at greatly reduced pressure or increased speed do not justify standardizing upon the revised practice. At any rate, haphazard cut-and-try methods are to be condemned. It is particularly important to observe that frequently there is a pressure which is just right, and that an increase or a decrease of more than one or two pounds will lead to definitely inferior cutting conditions.

Although many steels are very uniform in quality, as may be seen from Fig. 4, many vary sufficiently in quality, as represented by Fig. 6, that the operator must be constantly alert to properly evaluate the cutting variables in terms of the particular steel involved. If this is carelessly or ignorantly attempted the best possible cuts of the maximum possible economy are not likely to be obtained. Consequently, the following methodical procedure is presented:

1. A cut should be made with the particular tip size, speed of cutting, and oxygen pressure which are listed in some appropriate cutting guide, such as that supplied with the torch.
2. Examine the top edges of a cut and adjust the preheat accordingly (see discussion below).
3. Examine the "drag" of the cut and vary the speed of the cutting until a satisfactory drag condition is obtained.
4. Next, in executing successive cuts, gradually decrease the oxygen operating pressure making corresponding reductions of speed from time to time in order to maintain the drag desired.
5. Try the next smaller size tip, making use of a pressure about equal to the pressure listed in the cutting table for the thickness of metal being cut.
6. Repeat operations 3, 4 and 5.

For all of the above operations the various cuts made must be compared as to both quality and cost of cutting. Obviously, the cost of cutting must include the cost of the cutting oxygen, the cost of the preheat oxygen, the cost of the fuel gas, the labor costs and the overhead. Frequently it is also necessary to include the cost of the metal removed during the cutting operation. See section on "Cutting Efficiency."

In the procedure given above it will be observed that varying the speed of traverse is given preference over varying the operating pressure, and varying the operating pressure is given preference over changing the tip size.

There may be occasions when it is possible to omit one or two of these steps, that is, it may be possible to accept the given cutting speed and merely vary the cutting pressure, or it may be possible to accept temporarily both the given cutting speed and the specified pressure, and first of all experiment with different tips in trying to improve upon the approximate conditions listed in the table. However, it is important to understand that the order of procedure listed above is based upon a full recognition of the effects of variations in cutting variables upon the economy and quality of cutting, and is the most dependable method of arriving at satisfactory results.

There is some considerable interdependence between the preheat requirement and the speed of cutting or other variables. Therefore, in the above list of operations let it be assumed that the operator is familiar with the fundamental preheat requirements, and continuously makes such readjustments as are essential to maintain a proper degree of preheat. The preheat requirements are that the preheat shall be just adequate to continuously propagate the cut and sufficient to avoid backfire troubles.

In reference to the former requirement it is implied that very low values of preheat sometimes are inadequate to keep the upper surface of the steel at a sufficient temperature that the cold jet of oxygen will be able to energetically disintegrate the steel. Secondly, that the preheat should not be so great as to excessively melt the upper corners of the cut. In general, if an appropriate style of cutting tip is employed, the range of practicable preheat intensities for the tips selected will be entirely adequate to meet these requirements; it merely calls for adjustment of the preheat intensity by means of the torch needle valves.

A likely type of trouble in event of insufficient preheat is that of backfiring. Of course, if a flash occurs an investigation should first of all be made as to whether the preheat flames are balanced, the gas passages are clean, and the terminal condition of the preheat orifices satisfactory. If all of these conditions are satisfactory, and if flash troubles continue, it is quite possible that an effort is being made to use too light a preheat for the given cutting tip. There should be sufficient margin between the preheat in use and the excessive preheat that will cause the melting of the top edges of the cut that it will readily be possible to adjust the tip to a more satisfactory preheat condition.

There are times particularly with certain alloy steels, when the cutting conditions specified in cutting tables will be inadequate. The recommended procedure in such event is to assume that the steel is thicker than its actual size and to choose cutting conditions from the table accordingly. If such conditions prove inadequate it could be assumed that the thickness of the steel is even greater and again select appropriate cutting conditions from the table.

If the steel is quite rusty or scaly, it may develop that the preheat intensity when using a light preheat type of tip is inadequate. In such an event a heavier preheat type should be employed. Otherwise, the cutting conditions are unaffected.

## EFFICIENCY

The best means of rating the oxygen efficiency appears to be in terms of the oxygen requirements per square inch of metal sectioned by the cut. Such a figure is frequently designated as the "specific oxygen requirement." The efficiency on this basis of good commercial cuts is approximately as follows:

**Table 3—Specific Oxygen Requirements for Good Commercial Cuts**

| Thickness Inches | Cu. Ft. Oxygen Per Sq. In. Cut |
|---|---|
| 1/2 | 0.04–0.07 |
| 1 | 0.06–0.11 |
| 2 | 0.08–0.15 |
| 4 | 0.11–0.20 |
| 6 | 0.13–0.25 |
| 12 | 0.20–0.40 |

The above figures merely apply to the cutting oxygen requirement. The figures will be increased by 0.01 to 0.03 if the oxygen for the preheating flames is included. This is on the assumption that the preheating gas is acetylene. If the preheating gas is hydrogen or city gas, or one of the liquefiable hydrocarbons, the figures may be increased by a greater amount.

Figures on relative labor and overhead will, of course, need to be considered in addition to the figures on the oxygen consumption. Obviously the labor and overhead will be decreased as the speed of cutting is increased.

Figure 7 indicates that for 1 inch cutting with a No. 56 orifice the cutting-oxygen rate of consumption increases almost in direct proportion to the speed of cutting (so long as only one size of tip is considered). Note, however, that the upper portions of the curves of Fig. 7 take on decided upward curvatures at the higher speeds, indicating that the rate of oxygen consumption increases more rapidly than the rate of cutting at the higher speeds.

By selecting typical figures for labor, overhead, fuel gas and oxygen costs it has been shown that an operator may usually work well beyond the limit of proportionality and actually rather closely approach the speed at which the minimum drag is equal to the desired drag without running into uneconomical operations.

The foregoing has neglected the question of the quality of the cut. As the speed of cutting is increased the ultimate limit for a given tip may be imposed either by economic considerations alone, or by the appearance of the cut. In the former case the tip is used at a speed great enough to cause the "minimum drag," characteristic of the given tip, to be almost if not actually as great as the length of drag selected as standard, and the operating pressure is set just low enough to obtain the standard length of drag. In the latter case speeds as high as this sometimes prove impracticable because of the tendency of the quality of the cut to deteriorate with increasing speed of cutting.

If the appearance of the cut is very important it is generally the controlling factor for cuts less than two inches in thickness. For intermediate thicknesses one or the other factor may prevail. For thicknesses over 6 or 8 inches there does not appear to be any substantial difference between the two different limits, and economical considerations alone may be employed in selecting the proper tip size, speed and operating pressure.

When the limiting speed (economic or otherwise) of a given tip has been reached it is obvious that other sizes should also be systematically investigated. Another size of tip might afford even better results. A smaller tip, for example, will in general give rise to a narrower kerf and because there is less metal to be oxidized the oxygen requirement per unit area of the metal cross section will be decreased. It is also true that the wastage of metal will be less. In the case of heavier thicknesses and sometimes even for lighter thicknesses, it will be found that the cost of the metal removed from the kerf when valued at scrap prices is an important element in the cost of making the cut.

A larger tip might permit a much higher speed of operation, and consequently sufficiently decrease the labor, overhead and consumption of fuel gas as to offset the increased oxygen discharge characteristic of the larger tip. A careful analysis, such as illustrated by Fig. 8, should be made to determine which size of tip is best suited to the work at hand.

For example, the studies of Fig. 8 indicate that in the case of 2-inch cutting and for ordinary labor, material, gas and overhead costs, the smallest tip is the most economical if all tips are operated at maximum efficiency.

In actual practice, it is usually necessary to derive the cutting oxygen flow from the tip calibration and the pressure gage readings if one is to make use of analyses of the type just discussed. A calibration of the cutting tip may be obtained from the manufacturer of the tip, who can also furnish approximate values for the preheating consumption.

## CUT QUALITY

When the drag lines are irregular, such as are illustrated in Figs. 9 and 10, a condition is encountered in which it will be found that the faces of the cut are often badly grooved, concave, or otherwise irregular. Such drags are frequently due to foreign inclusions rolled into the plate. Note the correspondence of level for these inclusions (see photo of etching) and the discontinuities in the drag-lines.

However, abnormal cuts may also make their appearance when a tip, which is apparently in normal condition, is used. In such cases the trouble may sometimes be overcome through the use of a lower speed of cutting and a lower operating pressure. A very high operating pressure is particularly liable to cause horizontal flutes (which are the result of flow nodes in the cutting jet).

The following is a list of the most important conditions which should be maintained in the interest of smooth cuts:

1. Uniformity of torch movement
2. Uniformity of oxygen pressure regulation. (Important for heavy thicknesses and cold weather cutting.)
3. Uniformity of steel being cut
4. Smoothness of bore and proper type of cutting orifice
5. Cleanliness of orifice exit
6. Sufficiently high oxygen purity
7. Sufficiently low oxygen operating pressure
8. A gradual increase of speed when starting the cut in very heavy thicknesses
9. Sufficiently low operating speeds for light and moderate thicknesses
10. Sufficiently high operating speeds for heavier thicknesses

Excessive speeds are more commonly used than insufficient speeds in the case of light thicknesses (and the resulting cut quality is poor). However, it has been found that in the case of the greater thicknesses (over 4 inches) a ragged condition of the lower portion of the cut is sometimes encountered which is characterized by vertically disposed puckers, and which is due to insufficient speed. In increasing the speed, it will obviously be necessary to use a larger tip unless the change in operating speed is quite moderate.

Preferably, there should be no slag adhering to the bottom of the cut, and this is sometimes possible with the lighter thicknesses. A lightly adhering slag condition is favored by the following conditions:

1. Cleanness of cutting orifice exit
2. Smoothness of cutting orifice
3. A high purity of oxygen
4. Scale or rust along the bottom edge of the material being cut
5. Sufficiently high oxygen operating pressure (see Fig. 5).
6. Sufficiently large tip

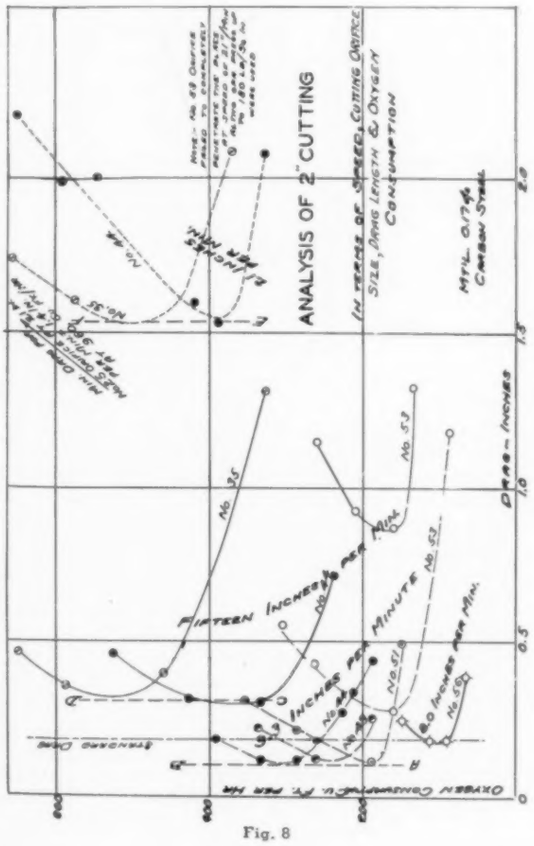



Fig. 8

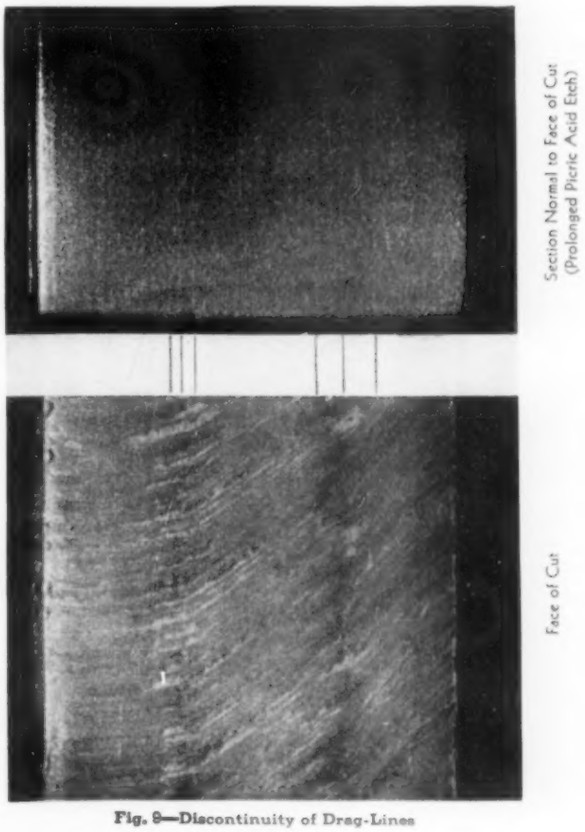



Fig. 9—Discontinuity of Drag-Lines

In extreme cases a larger tip may be employed than the most truly economical cutting tip. When considering such a procedure one should be sure as to whether the increased cost of operating the larger tip would be justified as compared with the cost of slag removal by mechanical means. If one side of the steel is rusty it is better to turn the steel so that that side is lowermost. The slag does not adhere as tightly to rusty steel as it does to clean steel. On the other hand, the upper surface of the steel should be as clean as practicable in order to minimize the preheat requirement.

medium sizes of tips, that is, tips suitable for thicknesses up to 8 inchs or 10 inches, the operating pressure should not exceed 40 lb. provided flat cut faces are actually required. This is upon the assumption that the hose lines and approach passages of the torch are adequate in the case of the heavier gas flows.

Precision shape-cutting also demands that attention be given to the question of thermal expansion. Lack of precision may result either from warpage of the material in event that thin sheet or plate stocks are involved, or it may result from a shifting of the plate during the progress of the cut as the result of the heat of the cutting operation. One should, therefore, carefully plan the operation so as to minimize these effects. For instance, it is desirable to eliminate, if possible, narrow sections of metal that may become overheated.

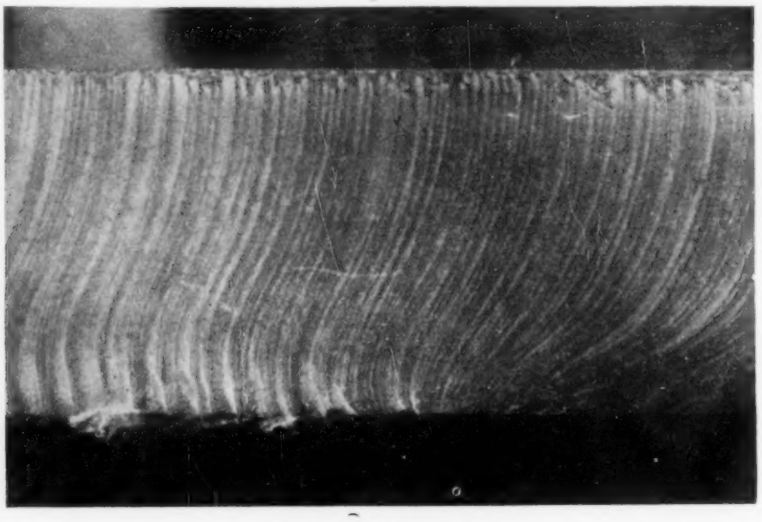


Fig. 10—Erratic Drag-Lines

Where the torch is held rigidly and advanced at constant speed, as in machine-guided oxygen cutting, across-the-cut tolerances may be maintained within narrow limits. In ordinary steel of 6 inch thickness, cut surfaces can be held true, as to cross-sectional squareness, within $^1/_{32}$ inch. Cuts in thinner sections can be held within smaller limits. The degree of longitudinal precision of a machine-guided torch cut depends on the trueness of the guide rails of the cutting machine, the clearances in the operating mechanism and the regularity of the propelling unit.

The squareness and planeness of cut faces depend to a considerable extent upon the operating pressures employed. For best results the operating pressures for smaller sizes of tips should not exceed 30 lb. and for

### SUMMARY

Because efficient and high-quality oxygen cuts depend both on the use of proper equipment and upon a proper cutting technique, this paper first of all attempts to point out specifically just what standards are essential in the selection and the care of oxygen-cutting equipment, and then precisely what systematic procedure is necessary to take full advantage of such equipment.

# Welding and Cutting in Machinery Construction*

By JOHN D. GORDON†

INSTEAD of the formal presentation of a paper we are planning to show a motion picture film dealing with the fabrication of special machine bases through the use of arc welding and rolled steel plate.

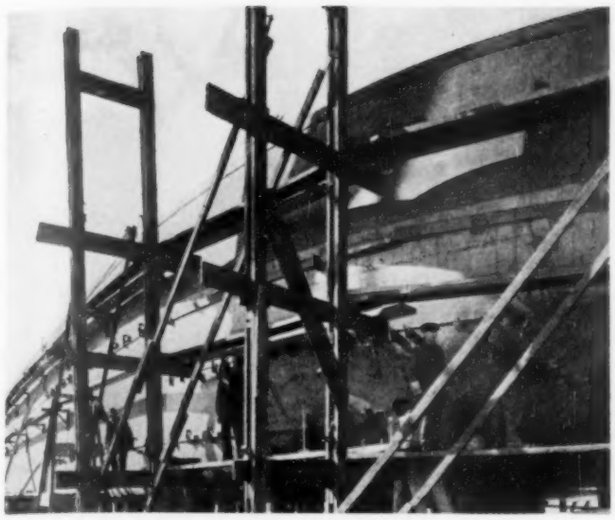
In order to give a clear picture of the various steps necessary in the production of bases for special machinery by fabricating, we have produced a 16 mm. film, 1600 feet long, starting with the necessary redesign encountered in changing from previous practice of either cast iron or cast steel into the fabricated steel structure.

Starting at this point, we proceed through the necessary detailing, laying out of templates for flame cutting the necessary steel plate using both temporary, paper templates, or aluminum bound plywood permanent templates for multiple pieces. We show the cutting and construction of these latter templates, and proceed from this point to the necessary stock of steel plates, bars and shapes that must be carried in stock in order to permit of the short deliveries which are made. We then show the actual operation of flame cutting machines, both single and multiple torch, giving a complete picture of the flexibility of this type equipment including stack cutting and three dimension cutting, on to the necessary chamfering of plates with a special flame cutting machine for this operation, through the necessary

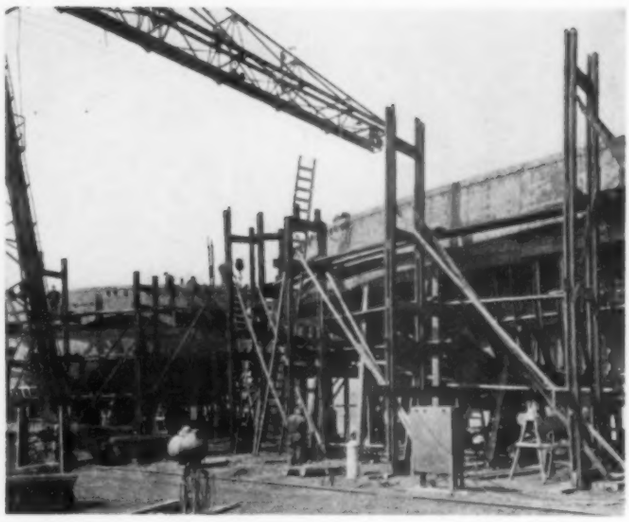
(*Continued on page 43*)

* Paper to be presented at Annual Meeting, A.W. S., Detroit, Mich., Oct. 16 to 21, 1938.

† General Manager, The Taylor Winfield Corporation, Warren, Ohio.



Simple Clips Used to Fair Shell Seams



Fitting Shell Plating to Bow and Stern

# ERECTION SEQUENCE AND WELDING

## Procedure of All Welded Lake Freighters*

By R. W. BRENDLE†

ABOUT 20 years ago, welding was first introduced in the shipbuilding industry in the Great Lakes area; and, until the advent of the shielded-arc electrode, the two major classification societies, The American Bureau of Shipping and Lloyd's Register would not accept arc welding for joining or repairing strength members of ships.

However, shortly after most of the bugs had been removed from shielded-arc welding, we had a large repair job on the dry dock which necessitated the removal of several frame sections of heavy ten inch ship channels. We proposed to cut these frames out, straighten them and replace them, welding the butts. This proposal was met with flat refusal to even consider such a procedure. However, we persuaded Lloyd's representative to at least witness some tests of butt welds in this same type of channel.

You know the inevitable result; the channels were tested to destruction with the actual weld remaining intact. Needless to say, we were allowed to weld the frames.

This was the entering wedge, and probably had more to do with the general acceptance of welded strength members by the classification societies in the Great Lakes area than any other welding done up to this time.

From then on our task was a bit easier and a short time ago we were awarded a contract to build two ships. These ships were to carry package freight from Detroit through the New York State barge canal to Atlantic coast ports. About six years previous to this, we built for this same customer two riveted ships, to be used in the same trade,

The Green Island on Her Trial Trip

and, due to the fact, that they would have to pass through the New York State barge canal their maximum size was definitely established. They were 300 feet in length with a beam of 43 feet, this being the largest vessel that could pass through this canal safely. However, our customer specified in the new contract that it would be necessary for the new ships to carry more cargo than the others, maintaining, however, through necessity, the same overall dimensions.

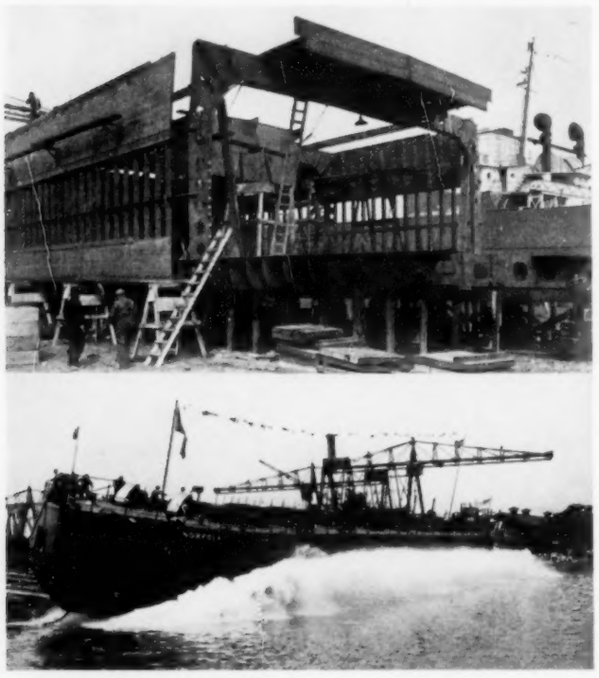
There was but one logical solution to this problem, and that was an all-welded ship. Our original estimate and bid for the building of these ships was based on riveted construction and when we took up the subject of an all-welded ship with our customer at no increase in cost, they agreed to accept this type of construction.

The first work to be done in the building of a ship is the designing and making of drawings in the drafting room; the many details were worked out and a general set of drawings were made among which were the lines of the ship. These general drawings and lines were then

* Paper to be presented at Annual Meeting, A. W. S., Detroit, Mich., Oct. 16 to 21, 1938.

† Welding Foreman, Great Lakes Engineering Works, River Rouge, Mich.

View Showing Web Frames, Arch Section and Plate Floors



Ships Are Launched Sideways on the Great Lakes

sent to the mold loft, which is a large building having a smooth wooden floor on which the ship is drawn out in full size. The lines are then carefully faired so that the form of a ship after it is built will be perfectly smooth. After the molds, templates and patterns are made they are sent to the shipfitters who mark off the steel by these means in order that the same may be sheared, planed and shaped.

About eighty per cent of these ships were laid out in this way, the other twenty per cent being lifted from the ship after the general steel work was erected.

In general the transverse construction of these ships did not lend itself to preassembly as well as longitudinal framing would have done; however, the following sections were assembled and welded in the shop and on the ground before erection: all floors, web frames, all foundations, skylights, transom and cant frames, pilot house well, bulkheads, arches complete with deck between hatches, pilot house, rudders, smokestacks, masts and any other small parts which could be welded into larger units, limited, however, to our crane capacity of fifteen tons. After a sufficient amount of steel had passed through the shop and was stacked alongside the building berth, the actual construction of the ship on the ways was started.

All bottom plates were used full size as received from the mill. The ends of the plates were beveled for 60 degrees single vee butt welds welded from top. Under side of butt chipped with round nose tool and closing bead applied. The keel plates were laid on blocks lined up and butts tackled. About six inches of butt at center welded and chipped flush where crossed by center keelson. The center vertical keelson plates were then erected, starting at center of ship and tacked to keel, being held vertical by temporary brackets on one side.

The "B" and "C" strakes of bottom plating were then laid on the blocks starting at the center of the ship. The middle butt of keel and center keelson plates were then welded. The center keelson plate welded to keel for length of one plate fore and aft of welded butt. One more butt of each plate was then welded and next center keelson plate was welded to keel.

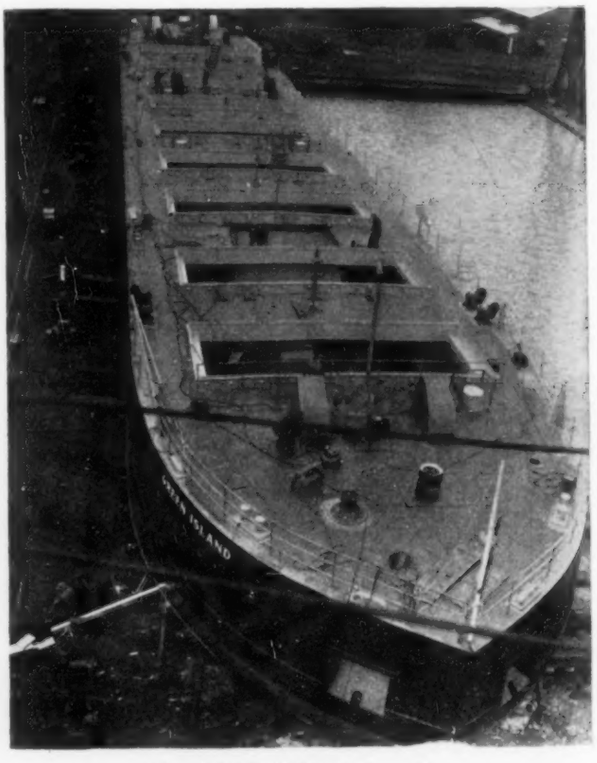
The erection of floors was then started working uniformly on both sides of the ship. Floors were welded to center keelson and tacked to bottom shell. The intermediate longitudinal plates were fitted in place and tacked as fast as floors were erected.

As soon as 12 floors on each side were welded to the center keelson, one tank top plate was laid on each side and tacked to center keelson and floors. The floors were then welded to shell and tank top. The first shell and tank top butts were welded and welding of the shell and tank top longitudinal seams was then completed for one plate length and further assembly was continued along the same lines. The second strake of tank top plating and margin plate was laid as soon as the tank top rider plate was welded to the floors.

When the tank construction had progressed sufficiently, the amidship arch and two amidship bulkheads were erected and plumbed. Two shear strake plates with attached frames were erected on each side and frames were welded to tank top. The bilge plates were erected and welded as fast as frames were in place. After deck assembly between hatches was completed on the amidship bulkheads, two spar deck stringer plates and the amidship length of gunwale bar was erected. The amidship butts of shear strake and spar deck stringer were then welded and deck assembly welded to stringer. When the construction between bulkheads was tied together erection was continued fore and aft in this same manner keeping erection about one hatch space ahead of the finish welding.

The side plating between bilge and shear strakes was then erected and welded, working fore and aft from amidships and keeping one plate behind the shear strake. All butts were welded before seams.

At the ends of the ship beyond the double bottom, floors, frames, beams and stringers were erected and



Completed Hull Prior to Launching

faired and all connections welded, the thickness of the shell plating was reduced to facilitate handling and fitting. The keel plate, shear strake and deck stringers were erected and welded before remainder of shell. All shell and deck plating was worked out toward the ends so that the last plates fitted were at the extreme bow and stern.

In general the welding was started at the center of the ship working outward to port and starboard and fore and aft, welding everything as you came to it. All butts were welded before the next plate was held by any

**The Norfolk Laying at the Fit-Out Berth**

seam welding and erection was kept about two days ahead of the welders. Any contraction athwartships in the bottom plating was adjusted in the lapped seams. In the tank top one strake on each side was left off until all piping had been installed in the double bottom and the width of this plate was adjusted to suit. Any measurable contraction longitudinally was adjusted in the last dead flat plates at each end. Bulkheads were left long and trimmed to size after they had been finish welded on the ground.

Downhand welding was used wherever possible, but due to the transverse construction of these ships and our limited crane capacity most of the welding was done in place.

Since we have built two riveted ships and two welded ships of the same type, and for use in the same trade, we are able to make some interesting comparisons.

First, there is the matter of cost of construction. The average cost per ton of steel erected was practically the same for the all-welded ships as for the riveted ships. When you consider that these were our first all-welded hulls and that we have been building riveted ships for over thirty years, one can readily see the possible savings after we become accustomed to this type of construction.

Secondly, I would like to point out the lack of vibration in an all-welded ship. During her trial trip, the "Green Island" was so steady that while going along at full speed on Lake Erie a coin was balanced on edge on the dining room table which was just aft of and over the engine room.

Then there is maintenance and repair. It is hard to predict what the cost of repairs will be on a welded ship. This will be governed entirely by the demands made by the classification societies. It is doubtful if they will allow us to use a shell plate; for example, which has been torn through collision or grounding, and until they have had a lot of past performance to go by in the repair of welded ships, they may order more extensive repairs than we think is actually necessary. We dry docked the Green Island after a minor grounding, and although she had a number of indentations in her shell plating, all welds were intact and she was still watertight. We were able to fair up these places without removing the plating, but had this been a riveted ship we would probably have had to remove three or four shell plates due to loose rivets, and this would have cost many times more than the work we did do.

Last and probably most important is the fact that these welded ships do have a big advantage over their riveted sister ships in that they are able to carry approximately 320 tons or 15% more cargo at the same loaded draft.

**General Information**
**"Green Island" and "Norfolk"**

| | |
|---|---|
| Length | 300 ft. |
| Beam | 43 ft. |
| Draft | 12 ft. |
| Depth | 20 ft. |
| Freeboard | 7 ft. 6¼ in. |
| Deadweight | 12 ft. 6 in. waterline 3210 tons |
| Gross tonnage | 1946 |
| Net tonnage | 1603 |
| Light displacement | 1203 |
| Tons of steel used | 885 |
| Pounds welding wire used | 30,000 |
| Oxygen used | 155,000 cu. ft. |
| Acetylene used | 36,000 cu. ft. |
| Lineal feet of welding | 90,000 |
| Preliminary work | 24 days |
| On building ways | 89 days |
| Fit out | 35 days |
| Total number of working days to build ship | 148 |
| Power | Two 560 H.P. Diesels, twin screw |

# Flame Hardening*

By JOHN SHEPPARD†

FLAME hardening has been appropriately defined as the process wherein the surface of a ferrous metal capable of hardening by heat treatment is locally hardened by rapidly heating to a temperature above the critical point with an oxyacetylene flame and then quenching from that temperature. This results in a hard wear resistant surface with a core which has not undergone any thermal change and, therefore, retains all its original toughness and ductility. There is no chemical change in the hardened surface and the process must, therefore, be differentiated from case hardening, Chapmanizing carburizing or nitriding, and other processes in which the surface composition is changed to render the material more hardenable.

The method is not new, the literature dating back almost to the first application of the oxyacetylene flame to steel welding where hardening of the metal adjacent to a weld in medium carbon steel was observed. Recently, however, the development of suitable mechanically operated water-cooled tips and torches which insure accurate control and dependable operation have given impetus to the use of the flame hardening process in industry. The hardening effect obtainable is similar to controlled atmosphere furnace hardening practice provided that the material has been heated to the same temperature in each case. The hardness can be tempered as required by a second and more gentle heating.

Machine designers are often confronted with the problem of selective wear of machine parts which often relegates a machine to the scrap heap through failure of one

* Paper to be presented at Annual Meeting, A. W. S., Detroit, Mich., Oct. 16 to 21, 1938.
† Chief Metallurgist, Kelsey Hayes Wheel Company, Detroit.

or two parts while the body is still intact and serviceable. Replaceable wear plates or liners of hard metal are inserted at points subject to selective wear, presenting a hard surface to concentrated frictional load and permitting the body of the machine to be made ductile and shock resistant.

Case hardening by the addition of carbon to form a thin hard layer on selected areas is a very old technique. It necessitates heating the part to 1600-1700° F. and holding for approximately one hour for each 0.010 inch depth of case desired, followed by quenching. This results in severe distortion which limits its application to small and simple shapes, and where selective case hardening of definite areas such as the contact surface of gear teeth is required, an elaborate and costly operation of electroplating the areas to remain uncarburized must be employed.

The materials used in machine construction, medium carbon steels, semi-steels and alloyed cast irons are capable of being hardened by suitable heat treatment. Such furnace hardened parts have been commonly used as tools or inserts in machines and the hardening procedures for improving their wear resistance are commonly known to metallurgists. Furnace hardening suffers the same limitations as case hardening as regards the difficulty in preventing distortion in large or complicated shapes. A further disadvantage is that the hardness cannot be confined to the wearing surfaces of the part, but extends into the body of the material causing an appreciable loss in ductility and in resistance to shock.

The application of the intense heat of the oxyacetylene flame provides a ready solution to the problem of obtaining the hardness effect of a furnace heat treatment at the wearing surfaces of a machine and retaining the necessary shock resistant properties in the machine body.

It provides the high surface hardness of a case or carburizing treatment with the toughness of a quenched medium carbon steel. Distortion and residual hardening strains are all reduced to the minimum. The microstructure shows no sharp line of demarcation between the hardened zone and the core as often found in case hardened work. The hardened zone produced is at least two or three times the depth economically obtained by carburization and there is a tapering of the hard martensite at the surface which gradually changes through troostite and sorbite to the ductile pearlite of the core which results in complete freedom from spalling under impact or vibration.

Plain carbon steels above 0.35% carbon are readily flame hardened. The standard S. A. E. water hardening steels or low-alloy oil hardening steels can also be successfully hardened. Increasing carbon content favors higher hardnesses. S. A. E. 1040 steel will readily yield Rockwell C 52–58 (600 to 750 diamond Brinell) with a vigorous quench. Rail steels of 0.80% carbon are flame hardened to 450 Brinell with a very mild quench, rapid quenching yields a hardness of 800 Brinell equivalent to the hardness of hard-facing materials similar to stellite.

Cheap carbon steels flame hardened have been used with excellent results to replace expensive alloy steels formerly required on many applications to provide the necessary wear resistance. In flame hardening, if the surface layer being heated is only a small portion of the total bulk, the quenching action is much more drastic than if the entire piece were heated and quenched. The amount of heat which the quenching medium must absorb is so much less that the quenching rate is tremendously accelerated, and Brinell hardnesses of 50 points higher than the furnace quenching method are obtainable when medium heavy sections are flame hardened.

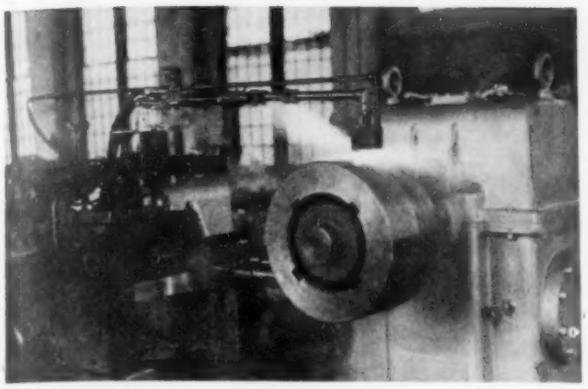
In hardening high-carbon steels in the tool steel range some care must be used to avoid surface checks from too rapid application of heat or a too severe quench. Only a fraction of the care used in furnace hardening these steels is needed when flame hardening for the tough unheated core provides an excellent support for the hardened face. Pearlitic malleable castings and low-alloy cast irons can all be successfully flame hardened. For many applications air hardening steels can be used which do not require any liquid quenching to obtain hardness after heating.

Flame hardening can be accomplished manually or mechanically. Small areas of a part can be raised to hardening heat by the application of a standard welding torch, the entire area being brought to temperature by moving the torch back and forth across the surface. The torch is removed when the operator judges that the temperature is right and the part quenched. This is the method extensively used in hardening rail ends to reduce batter. The entire width of the running surface of a rail and some four or five inches in length may be hardened in less than two minutes. Temperatures are determined by means of an indicating pyrometer having sturdy sharp iron constantan points which are pressed into the hot rail end to complete the thermocouple circuit. With a little practice the operator may learn to judge temperatures quite accurately by eye, an inexperienced operator invariably tending to underestimate the temperature and overheat the work. The degree of hardness produced can be controlled by regulating the volume of quench water. Results can be verified by means of a portable Brinell tester.

In hardening extended areas such as the entire rail length or the wearing surface of the bed of a lathe, the hardening process is made continuous by incorporating both heating and quenching functions in the hardening tip, and providing means for moving the tip at a constant speed along the path to be hardened. Heating is accomplished by one or more rows of small oxyacetylene flames followed closely by a row of quenching holes. While water is the most common quenching medium, air and in some cases nitrogen are used.

The tip progressively heats the surface along the path of travel to hardening temperature, the quenching stream following closely imparts a uniform hardness to the area covered by the tip travel. Multiflame tips must be water cooled to prevent overheating of the torch and flash back of the heating flames. Tips 5 inches in width have been made for hardening wide areas, but it is usually more practical to use narrower tips, 3 inches in width and under, and to harden the surface in successive strips. Auxiliary water jets are applied at the ends of the rows of heating holes to prevent flow of heat into the areas already hardened. The soft line between two successive passes can be made so fine that it cannot be detected with the standard Brinell tester. The speed of tip travel may vary from 3–12 inches per minute depending on the size and number of heating holes and determines the penetration of the hardness. The usual speed is 6–8 inches per minute for one-eighth to three-sixteenths of an inch penetration. The degree of hardness obtained is regulated by the nature and volume of the quenching stream.

To provide for accurately controlled speed of motion of the hardening tip over the object surface, the torch can be mounted on a standard oxyacetylene cutting machine. The desired speed falls within the range obtainable with these machines and they are thus ideal traversing devices. The tool post of a lathe with variable feed can also be used as a torch holder. All that is demanded being a steady uniform rate of progress of the tip at a fixed distance above the work. Cylindrical surfaces six inches or more in diameter are hardened by mounting the object on the spindle of a lathe and fixing the torch



Flame Hardening an Outer Diameter Using a 3-Inch Flame Hardening Tip

in the lathe tool post. The peripheral speed of the surface to be hardened should be similar to the speed of travel over flat surfaces given above. Both internal and external surfaces of a cylindrical object can thus be hardened by progressive heating and quenching in one revolution. A row of water jets closely preceding the flames prevents drawing of the hardness at the completion of the circle.

Cylindrical shafts of extended length are hardened by rotating the shaft on a lathe spindle with the torch mounted in the tool post. The torch is fed slowly along the length of the shaft, the relative motion of the hardening tip being spiral to the shaft axis. As in hardening successive flat strips, auxiliary quenching streams are used to avoid drawing the hardness of treated areas.

Cylindrical surfaces either internal or external less than six inches in diameter are treated by spinning at 150 to 300 revolutions per minute in front of the water cooled multiflame tip. If the path to be hardened is too wide to cover with one tip several tips are employed. When sufficient time has elapsed to allow the work to reach hardening temperature the torch is shut off and the quenching water is turned on while the work is still spinning. For high production the lighting of the torch, the duration of heating and the timing of the quench are all regulated automatically by cam mechanism. The operator merely placing the work in the machine and pressing the starting button. With such an arrangement absolute uniformity of hardness and depth are obtained provided constant gas pressures are maintained at the tip.

Flame hardening tips can be obtained to fit irregular contours. In many cases, however, it is preferable to split up such a contour into several parts, and harden each part of the contour as a separate operation. The resulting simplifications in tip design considerably reduce their cost and promote easy operation.

The hardening of gear teeth offers one of the best examples of the flame hardening principle since only a limited area on both sides of a tooth at the pitch line must be hardened, it is possible to harden gears with practically no distortion, so that the gear can be previously finish machined in the unhardened state.

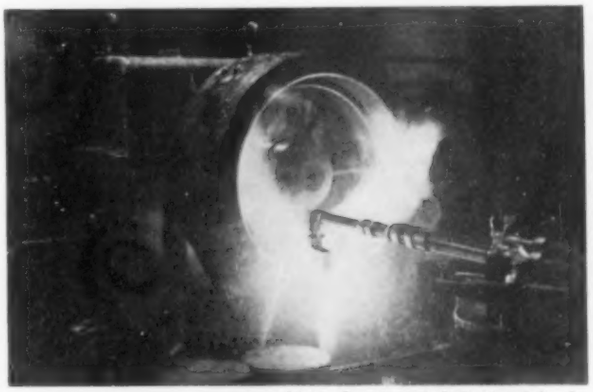
In hardening gear teeth, the tooth profile is divided into two parts and heating tips are designed to fit each half of the tooth contour. Spur, sprocket, worm and herringbone gears are hardened by mounting the tips in a yoke at a fixed distance apart and providing for uniform motion of the tips along the tooth. The torch is lighted and the quenching water turned on before the tip begins to traverse the tooth, when the path is completed the gas is shut off and the tip drawn back, the gear is revolved one tooth, the torch relighted and the cycle recommenced. Special equipment is required in the case of worm and herringbone gears to rotate the gears as the tips move in a straight line along the gear axis, and with bevel gears for varying the spacing of the hardening tips and the speed of torch travel to accommodate the varying cross section of the tooth. In hardening worm and herringbone gears use is made of a follower engaging between two teeth and thus fixing the path of the tips which are mounted separately and connected by flexible leads to the flame hardening torch. The gear is turned on its axis as the hardening operation proceeds. Gear hardening machines, incorporating these features have been built and are available for the production hardening of gears.

In spite of the apparent simplicity of the process a few fundamental points should be kept in mind in approaching flame hardening problems. If the exact composition of the part is not known a test-piece should be taken, and heated in a furnace to 1500° F. and quenched in water. Testing with a file or on a hardness testing machine will show whether the steel is hardenable or not. Should the material show no appreciable increase in hardness it is frequently possible to change the material specification usually by increasing the carbon content.

Wherever possible, fine grained steels should be chosen for parts to be flame hardened. Their inherent tendency to resist grain growth being a safeguard against over-heating by an inexperienced or careless operator. Their shallow hardening characteristics are no disadvantage to the process.

In order to derive complete freedom from distortion forged or cast parts should be normalized in the usual way before flame hardening. If maximum toughness of core is also desired normalizing should be replaced by furnace hardening followed by a tempering operation at 100 to 200° F. below the critical range. This is followed by finish machining and finally flame hardening, giving maximum surface hardness with greatest core toughness and freedom from size change.

A neutral flame setting of the torch is best and this combined with rapid quenching gives work which is as scale free as that coming from a controlled atmosphere hardening furnace. Heat input should be rapid which means that gas pressures should be high and torches and tips as large as possible. Low heat input permits wasteful loss of heat by conduction into the body of the metal resulting in higher gas consumption. Generally it will be found possible to harden 4 square inches of surface for each cubic foot of oxygen and acetylene consumed. Ample quenching volume should be used to secure high hardness. Simple trials easily determine the correct settings of torch speed, gas flow and rate of quenching to produce any degree of hardness and depth of penetration desired.



*Photos Courtesy Air Reduction Sales Co.*

Flame Hardening an Internal Diameter with a 3-Inch Flame Hardening Tip

# RECENT DEVELOPMENTS in the Welding of Machine Tools*

By L. F. NENNINGER† and W. A. MADDOX‡

THE fabrication of steel by welding has progressed very rapidly in the last few years. Progressive machine tool builders, like those in other industries, have investigated the possibilities of using this method of construction in their product. Additional work with welded steel structures has been predicated on their early results.

### MISTAKES WERE MADE

Naturally some mistakes were made in practically every field that welding has entered, because the initial efforts were not always properly directed nor intelligently supervised.

### PERFORMANCE OF WELDED MACHINE TOOLS

It is a pleasure to report that machine performance problems directly attributable to welding are quite rare and seldom indeed get past our "run-off" inspection. It is quite interesting to note here that only as short a time ago as 1931, Mr. Sol. Einstein, Vice-President of our Company, in a paper presented before the A. S. M. E. stated that "It would take years of experience, sometimes sad experience, before our knowledge in designing welded structures will reach the status which we now enjoy in cast-iron structures." While welding has hardly started to come into its own, the progress made certainly is far greater in a few short years than even such a progressive thinker as Mr. Einstein could visualize in 1931.

### WHAT IS BEING WELDED

Industry in general has accepted good welding in every branch of modern industrial civilization as a proven method of construction. Parts welded range in size from watch chains, parts for your automobile, on up to the very high pressure steam boilers and the steel work of towering skyscrapers. It would be a physical impossibility to build the modern sky liners or the flying fortresses without welding. The automobile costing from $700 to $1400 would cost you and I much more if welding could not be used. It is very easy to overlook what a tremendously important part welding plays in all of our lives, from day to day.

### RIGIDITY IN MACHINE TOOLS

Let us consider the matter of rigidity. This is a subject about which machine tool builders are indeed sensitive. How many times have we heard the remark that steel just won't do where rigidity rather than strength is the important consideration? In a particular case we had been using a $^3/_4$-inch wall section of cast iron. We calculated the corresponding section in steel, assuming that it could be done. Since modulus is the measure of rigidity, we tried to multiply $^3/_4$ inch $\times \frac{12{,}500{,}000}{30{,}000{,}000}$ getting 0.3, and then built machines with wall of $^5/_{16}$ or $^3/_8$-inch plate.

We found the structure to be flimsy. It was all warped out of shape by too much welding, and the bare rod weld-metal deposited was quite brittle and often cracked. Stress relieving was not understood and was often improperly done, if at all.

What was wrong with our theories? Was not modulus a measure of rigidity? Was there no way to produce stable structures? Were all steel structures to be noisy, subject to troublesome vibrations?

Let us consider what we have learned from our problems. When we stop and look at our present developments in welded machine tool structures and consider the weaknesses and errors of our first attempts at welding, we realize that the error was not in our theories, nor was it due to the material we used. The difficulty was primarily where we put this material, how we joined it to the adjacent pieces, and what steps we took to relieve the stresses after fabrication.

When we first started to substitute steel for cast iron we overlooked the basic fact that castings contained many ribs, generous fillets and the most vital condition, that is, one section blends into another in such a manner that all the surfaces, walls and ribs work together as one mass. The common frequency of such a structure is quite low, and in addition cast iron does indeed have a much lower response frequency than steel.

It is well known that cast-iron structures age and relieve their stresses even under ordinary use and condition. It is also known that the stress-strain curve of cast iron is not linear, namely the proportionality between the stress and the corresponding deformation or strain even at light stresses, does not follow a straight line. Consequently the deformation produced on any structure made of cast iron is partly elastic and part of it is plastic, thus resulting in a permanent set. This particular behavior of cast iron has been investigated by W. E. Dalby.‡

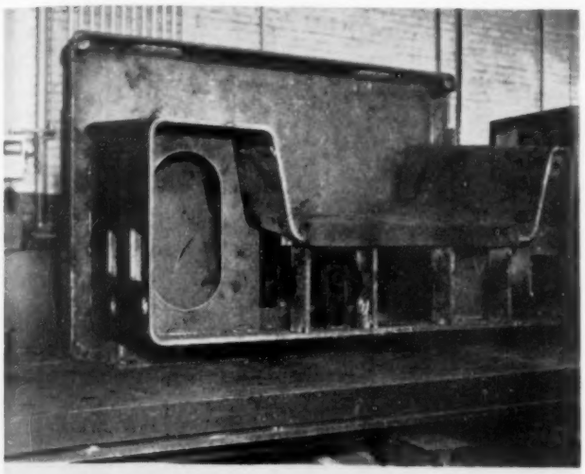
In the case of steel, the stress-strain relationship is represented by a straight line up to the true limit of proportionality, beyond which a slight increase in stress may produce considerable increase in strain. Now, if we have a welded steel structure, the stresses which are produced in it due to welding may be of such an intensity as to subject the structure to deformations obtaining beyond the limit of proportionality; therefore, the structure will be distorted, until equilibrium is reached between the stress and corresponding strain.

* Paper to be presented at Annual Meeting, A. W. S., Detroit, Mich., Oct. 16 to 21, 1938.

† Chief Engineer and ‡ Supervisor of welding, The Cincinnati Milling Machine and Cincinnati Grinders Incorporated, Cincinnati, Ohio.

‡ W. E. Dalby, *Phil. Trans. Roy. Soc.*, Ser. A, 221, 1920. A. E. H. Love Mathematical Theory of Elasticity, pages 114–115.

Fig. 1—View Looking Down Into No. 6 Centerless Grinder Bed Showing Internal Ribbing



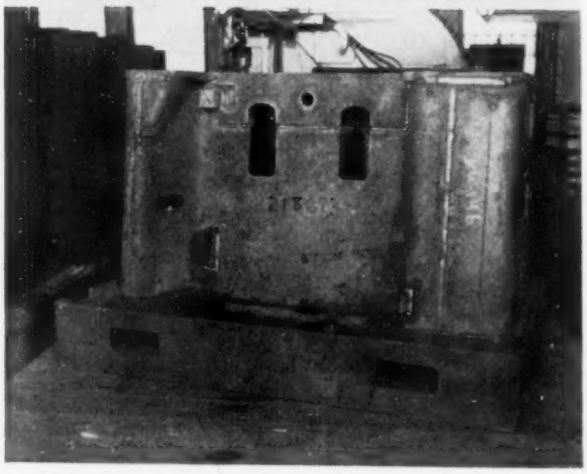


Fig. 2—Front View of Completed No. 6 Centerless Grinder Bed. Note Smoothness of Joints

The additional load, which corresponds to the residual stress, will cause a still greater permanent deformation. In order to avoid this condition, it is desirable to reduce the internal stresses to a point far below the proportional limit. The stress thus obtained, which can be called a residual stress, when added to external stress produced by a load under use, should not exceed the proportional limit; otherwise, when high loads are applied, we will produce a stress such as to cause a plastic flow and a permanent deformation will result. If then, by some type of stress-relieving process, the residual stress may be reduced to some value in the vicinity of 3000 lb. per square inch or less, a stable structure will be produced.

In the matter of thermal stress-relief, there is much experimental evidence available[1] to show that if we heat a welded steel structure through the correct heating and cooling cycle, holding it at approximately 1200° for a reasonable length of time (usually 1 hour/inch thickness), the residual stress will be below 3000 lb. per square inch. As discussed above, this value is so definitely below the proportional limit for steel that a stable structure is insured.

[1] Interpretation and Use of Creep Results, by J. J. Kanter, *A. S. M.* 1936 Convention. The Rupture Strength of Steels at Elevated Temperatures, by White, Clark & Wilson, *A. S. M.* 1937 Convention.
Stress Relief by Annealing, Research Supplement THE WELDING JOURNAL, Nov. 1937, page 38.
The Welding Handbook, pages 403–415.

This fundamental and essential difference in the plastic flow of cast iron and steel has a most important bearing on the use of welded construction.

In other words, if we build a good stable, accurate cast-iron machine tool and put it on a foundation that is not the best and the foundation settles, the cast-iron machine will take a set that is definite. Even if the trouble is corrected, the bed will still be out, until it is remachined or forced back into place by a new stress produced by clamping and jacking to make it take a new set. Steel on the other hand will, as shown above, after proper stress relief, be permanent unless forced past the proportional limit. Take a large stress-relieved flat steel bed, support it on three corners for an indefinite period, level it, then check it and it will not have taken a set out of flat. This is indeed a valuable characteristic.

## VALUABLE PROPERTIES OF CAST IRON

It would not be well for the machine tool builder to forget the really wonderful properties of cast iron. It is an almost ideal material for his purpose from many points of view. Its strength is more than sufficient for most requirements encountered in machine tool design. It has a deadening power and a most amazing ability to absorb vibration that no other suitable metal possesses. It has natural internal properties that enable it to dampen vibration set up by the various machining processes. It can be planed or milled to form a "way" or guide surface which is suitable for almost all applications. You are all familiar with machine tools 10, 20 and 40 years old whose scraped surface has not worn the few tenths of a thousandths of depth of the scraper mark. Early welded structures used bolted on cast-iron ways and such ways are still being used in some applications. The rigid and hard requirements imposed on production machine tools in high production shops in a number of cases has led to the use of hardened way surfaces. Whether this is justified for ordinary usage is a matter much discussed and is now being carefully considered.

This development is having one interesting result—it reduces the difference in cost between cast iron and steel for certain structures. This means it has become economical to place certain structures in steel which would have been made of cast iron because of the cost of applying separate slide way strips for the steel machine.

## THE DESIGN PROBLEM

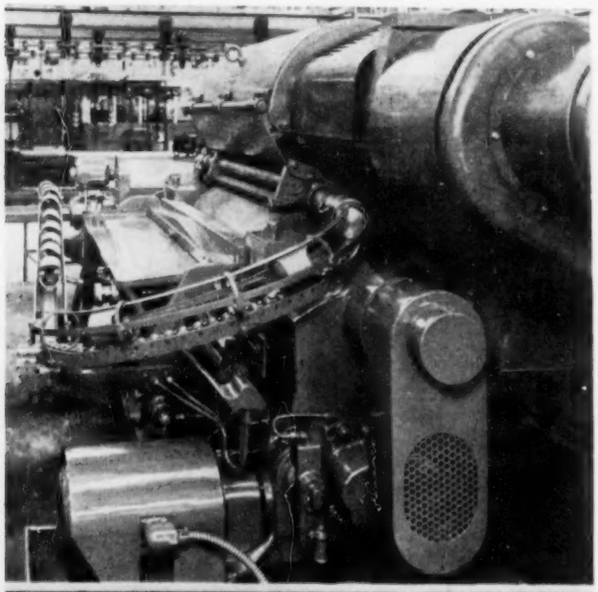
The designing engineer in fabricating a machine tool of steel has the problem of getting all the essential properties into the steel structure that are inherent in a good casting, the technique for the making of which has been many, many years in the development. For example, a big flat uninterrupted area is considered bad foundry practice, while such a flat slab is more or less inherent to steel. Nevertheless, such an area of cast iron is definitely more dead, more suitable for a machine tool structure than the flat steel plate of a corresponding size.

The average machine tool designer has worked so long with cast iron that to think in terms of steel requires extra effort. He has to strive to keep from thinking in terms of cast iron and then building the product of steel. It is like a foreign language, one does not become really proficient in speaking a foreign language until he learns to think in that language rather than think in his own, then translate it into the other language.

## APPEARANCE IS REALLY IMPORTANT

Just as the early cars had whip sockets, so early efforts in the use of steel construction were along the lines of

Fig. 3—End View of No. 5 Centerless Grinding Pistons in Customers Plant



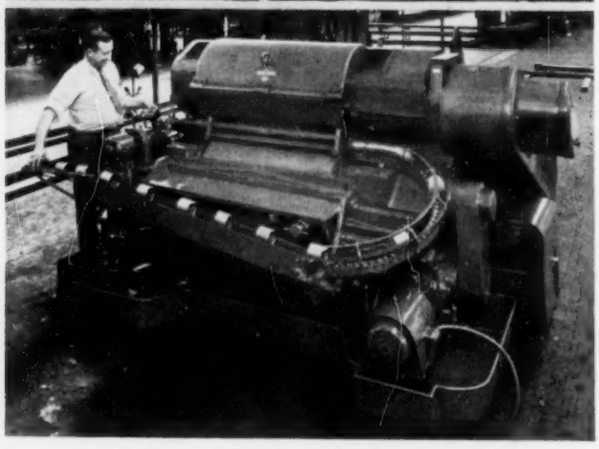


Fig. 4—No. 5 Centerless Used to Rough Grind Pistons in Customer's Plant

copying cast-iron structures or of going to extremes in box construction. We now recognize that just because a method of design or a style was good when applied to cast iron, it does not follow that steel is applicable in a like manner. True, some manufacturers demand cast-iron shapes for appearance sake and they get them in steel, but they pay the price and that price is not low. Times are changing; new shapes, lines, appearances, styles are with us. They may seem harsh and strange to us today, yet some of them will be the pace setters of tomorrow's styles. With as versatile a method of manufacture as welding available, we certainly cannot be content to build steel machines with lines and styles that looked up-to-date yesterday.

We feel that the proper thing to do is to establish styles and appearances that fit into the proper use of fabricated steel structures. Figures 1 and 2 are excellent examples of the possibilities along this line. This machine combines castings and welded steel to make a special purpose machine which, while not conventional, certainly is not displeasing to the eye.

We find in such machinery as this, that the shape, the lines, the massive suggestion of power, or rigidity is so definite, so positive that it gives one faith in the finished machine tool. You feel that it will function to your satisfaction.

## WELDED MACHINES

### *1. Grinders*

A full realization of the inherent possibilities of welded steel fabrication, so far as our Company is concerned, came after we designed and built the large CINCINNATI No. 6 Centerless Grinder of welded steel. This is a precision centerless grinding machine finishing pistons, for example, to limits of 0.0002 inch for size and roundness. The former cast-iron machine of the same design weighed over 9600 pounds for the main frame units alone which consisted of two pieces.

This grinding machine was made in two sections because of the lack of equipment to handle large work. Even at that, it was not a good casting to cast or machine. The up-to-date steel counterpart weighs 6600 pounds and is, of course, in one piece. This machine is producing finishes of the highest type at an extremely rapid rate of stock removal.

One application of these grinding machines employs 36 inch diam. wheels, 30 inches wide, driven by a 100 hp. motor. The performance of this machine is excellent and there has never been any problem of chatter, vibration or any of the other kindred ills sometimes attributed to welded steel machine tools.

Figures 1 through 4 are a series of pictures showing how this grinder is built up. The careful placing of metal exactly where it is needed should be noted, also the pleasing lines obtained by cold bending. This structure is so worked out that it is extremely rigid, yet its weight is

Fig. 5—Looking Into the End of a Fixed Height Rail Having Built-In Spindle Carrier. Used on Machine Shown in Fig. 6

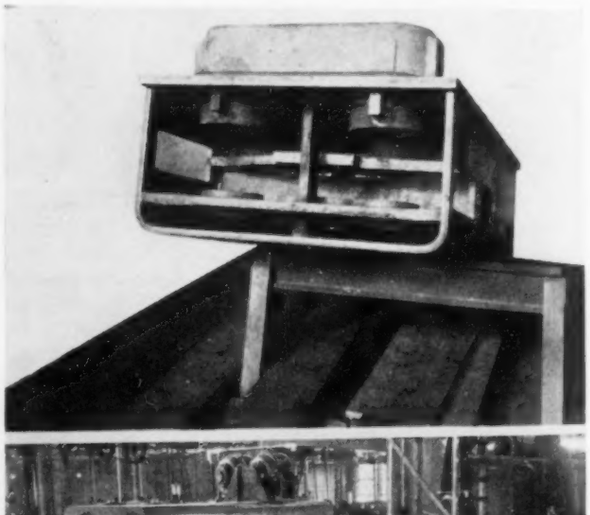


Fig. 6—Front View of Special Welded Steel Hydromatic. Only the Table Is Cast Iron

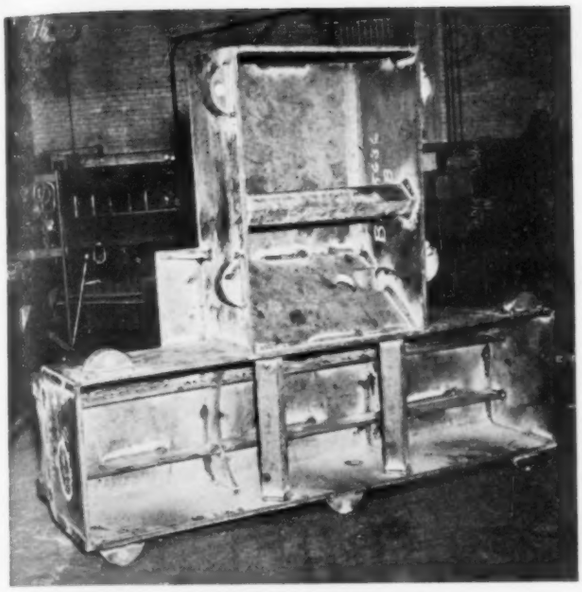


Fig. 7—Bottom View of Light Weight Welded Steel Hydromatic Milling Machine Bed After Welding. Note Bracing and Ribbing

moderate, and we are able to produce it with a saving in weight and cost.

*2. Milling Machines*

What can be done with welded steel milling machines where vibration is especially serious and where the average milling cut would tend to set up chatter? This problem is especially serious where intermittent cuts are to be made using one or more large inserted blade mills. Well do we remember one of our early efforts to fabricate a steel rail. It was to be used to carry standard spindle carriers for a used milling machine which we rebuilt for a customer. The vibration in this steel rail was terrible, the distortion under the cut was a disgrace, yet with it all the distortion was constant and the machine ran a full year. During this time we had learned much and when this machine was returned for rebuilding some of our problems and our errors were better understood and the answers were ready. Even so when considering the rebuilding of this machine a cast-iron rail was deemed best.

However, the excessive overhang, the insufficiently supported heads, the internal ribbing were all radically modified. In other words, the features that were really responsible for most of the trouble with the steel rail were properly taken care of when the rail casting was made. In the future, we would make that rail of steel (as we have numerous others) and know before we build it that it would be satisfactory, that it would weigh less than the cast-iron rail, and its construction of steel would carry all the interlocking advantages that comes from the fabrication by welding of this type of structure.

More recently, we built a special Hydromatic Milling Machine with four spindles for milling the seven surfaces of a small two-cylinder engine block. Figures 5 and 6 show this interesting machine tool.

Figure 5 is of particular interest because it shows intricate bracing used for additional rigidity. A number of shafts and large gears go into the compartment shown. The large steel casting is the spindle carrier proper. By use of this and the other three steel castings also shown, elaborate burning, welding and milling operations are eliminated.

Figure 6 is a view of the complete Hydromatic Milling Machine. We feel that this is a good looking machine tool and are told that it is giving excellent results.

In order to know just how rigid a welded machine tool can be, three very accurate reading dial indicators were placed on the outer corner of the fixed height rail carrying the vertical spindle carriers. The deflection readings were extremely low, definitely less than we could hope for on a machine with a cast-iron rail designed for similar work. The skeptics within our own organization, needless to say, felt much better about welding after this demonstration proved that a machine of welded steel was indeed very rigid. Further, a careful analysis as to the source of the small deflection we did find, taught us some things which will enable us to produce a similar machine lighter in weight and yet more rigid.

*3. Hydro-Tel Milling Machine*

Figures 9, 10 and 11 illustrate an excellent example of a large welded Cincinnati Horizontal Hydro-Tel. This machine which is of all welded-steel construction mills a difficult and interesting job. Present time for milling this piece is 8 hours with 45 minutes for hand dressing time. The time used to be 48 hours on a good milling machine, with 8 hours hand dressing time.

This bed is in one piece, eliminating the making of a bolted joint, yet its weight is moderate. The internal ribs are distributed according to the rigidity requirements at that particular section. We can build a bed 10, 15, 20, 25 feet long using the same equipment and design. In short, the sales department may sell a machine exactly suited to the customer's needs, and whether it is 10 or 25 feet long, we can fabricate it with equal facility. This has been our practice and is well exemplified by the use we have made in building the Hydro-tel.

We have built numerous machines with details partly or completely of steel. Figures 7 and 8 are views of another special steel bed Hydromatic Milling Machine. The Spindle Carrier is made as a casting because it is rather intricate. A casting was economical to use, especially so in this case, because more than one was to be made.

*4. Hydro-Broach Machines*

Broaching machines, single ram, double ram and large horizontal types all have set a new pace for production and accurate machining of plain and curved external surfaces. While their application is only in its infancy, a list of their users reads like a directory of the industrial

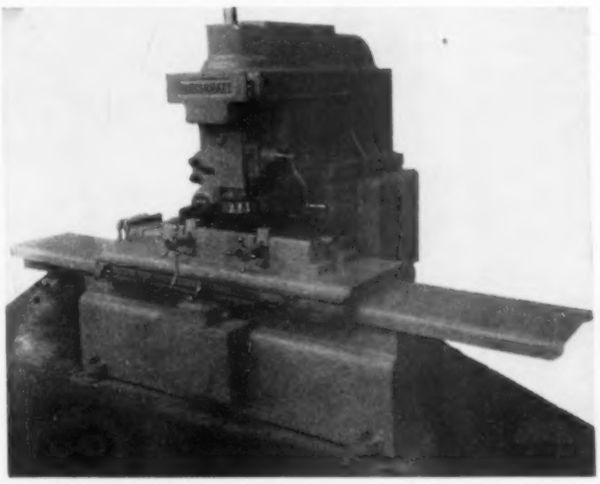


Fig. 8—Completed Hydromatic Machine. See Fig. 7 for Base. Consists of Cast-Iron Spindle Carrier with Intricate Ribbing and Brackets, Steel Spacer, Steel Bed and Steel Table

Fig. 9—Upsidedown View of Hydro-Tel Base, Showing Rib Construction Prior to Placing of the Bottom Plate

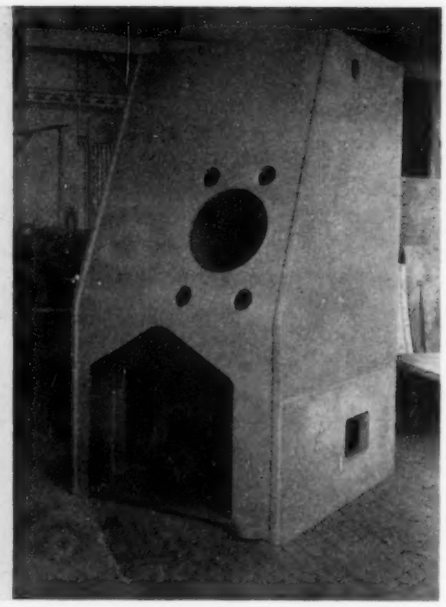


Fig. 10—Hydro-Tel Headstock, Showing Finished Painted Structure Prior to Machining

mass production shops. Parts ranging from auto door safety catches broached at 1200/hour on up to 8 cylinder motor blocks at 60/hour are all being broached today with machines having capacities of 2 to 150 hp., respectively.

How far welding enters into broaching machine construction is worth investigating. From beginning to end the construction of these marvels of modern machinery require welding.

Figure 20 shows what is probably one of the most nearly ideal welded machine tool beds it is possible to build from a cost point of view. It consists of 2 standard angles and a standard I beam. A few ribs of $^3/_4$-inch plate are welded into the bottom and 14 supporting feet are welded on. The amount of labor per pound of material is abnormally low, yet the rigidity is everywhere it is needed and in the correct plane.

The advantages of having such a design are numerous. Stock material is used and the cutting waste is very, very small. The component parts fit together without effort. A casting to replace this welded structure and do the same job would be difficult to cast and would be of doubtful stability over such a length, unless the depth of section is increased considerably.

Let us consider the giant cylinder block broach. As pointed out earlier, rigidity is vital, yet these machines are 33 feet, 10 inches long!

Figures 14 through 20 show this machine in various stages of construction.

The rough bed after welding weighs 26,000 lb. It is worth mentioning that it is cleaned up in $^3/_{32}$ inch over the entire flat surfaces. A cast-iron bed for this machine of satisfactory rigidity would weigh 39,900 to 45,000 lb. The trouble with making a cast-iron bed of this size is the difficulty of making such a casting.

These welded machines contain cast iron, sheet steel, steel plate, steel castings, forgings and heat-treated alloy parts; each form of metal applied where it is best suited to do the work required of it. The material chosen is dictated by its mechanical properties and the relative merits of each for the work and service that it is called upon to perform. In other words, our engineers are able to select the best material for each application.

Then, there is the broach work fixture for handling and holding the block. Strength as well as rigidity is of vital necessity here, yet it must have some pretty big openings, at embarrassing places for the cylinder blocks, piping, dust removal and operating details. In addition, the casting of the fixture would be complicated by the fact that each machine of this type is usually special.

In working out the operations, minor changes or rearrangements may be necessary. With steel, by the most carefully controlled procedure, we may make or enlarge openings or we can close up holes or move lugs and bosses. In other words, with welded steel fabrication, we have a freedom in design and manufacture that the engineer limited to cast iron can only dream of and hope for.

Then there is the hydraulic oil piping. To make screwed fittings for work of this nature would not only be quite expensive, but difficult mechanically, if not impossible. This piping is gas welded and the quality of such joints is well known. The chip troughs, oil catchers

Fig. 11—Showing Hydro-Tel, Consisting of a Welded Bed, Column and Special Steel Rectangular Overarm, Making a Type of Cut Prone to Set Up Unusual Vibration

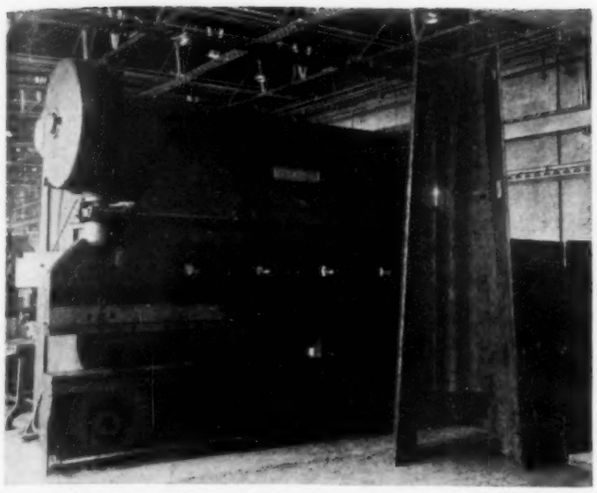


Fig. 12—View of the Main Structure of a Single Ram Hydro Broach. in Front of the Machine Used to Form It

and numerous other accessories so necessary to machine tools are bent up and welded.

No, there isn't much of a question, but that even the most ardent advocate of cast iron will grant that welded steel plays a really vital and necessary part in the construction of machine tools.

### WHAT DETERMINES THE USE OF CAST IRON OR STEEL?

After all is said and done why should we use welding in machine tools? There are many reasons, but they all boil down to just one; namely, that it is good, very good economics to weld certain types and classes of machine tools and details. There are machines whose inherent design features are such that cast iron is the proper material for their construction. This group includes machines built in large quantities and intricate in nature. Here cast iron is so completely suitable that other materials are not competitive in their present state of development. At the other extreme are special or semi-special structures which we cannot afford to cast for any of the numerous reasons stated in this paper. But the most important group of all, consists of the border line cases which were cast iron and which we have been changing over to steel as our knowledge and equipment expands. Strange to say, this last group is far more important to the welding shop than those machines that are definitely steel structures. The reason for this apparent abnormality, is that without obtaining much of the load for the weld shop that this competitive group carries, the weld shop and its personnel is seriously handicapped by two conditions. First and most vital is the lack of equipment. With a minimum of equipment a fabrication shop can build a machine tool base, column or rail for 12 to 14¢ a pound. On the other hand, a similar design, but one quite differently detailed and built using a reasonable amount of standard machinery such as plate shears, press brakes, punch presses, hydraulic presses, nibblers, circle shears, power cold saws and other machinery of this type, will be built for much less.

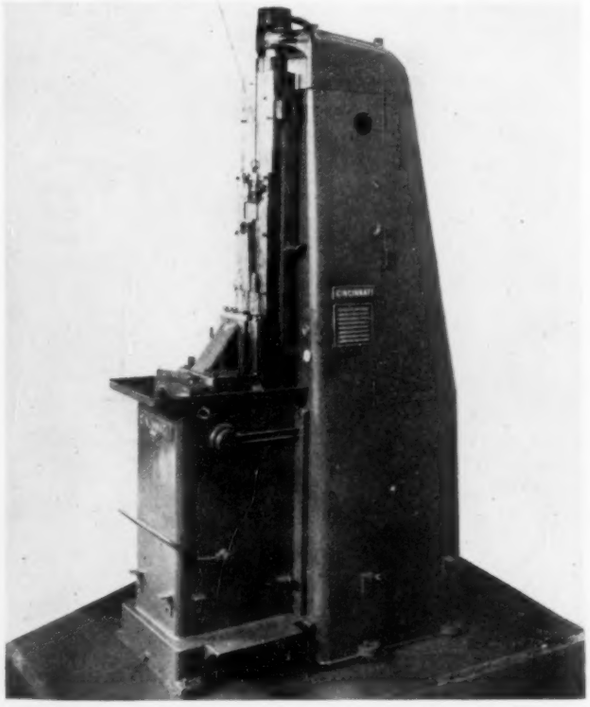


Fig. 13—View of Completed Single Ram Broach. Main Member Shown in Fig. 12

As foundry casting costs have gone up in recent years from 4 or 5 cents per pound to 6, 7 or 8 cents per pound the welded structure has become more and more competitive. While some factors have tended to increase welding costs, the actual finished cost of welded structures has been definitely on the down grade. This has been brought about by design trends and increased knowledge on the part of the engineer and the shop. The use of press brakes has been a very definite factor not only in reducing our costs but in improving the appearance of our machines.

Considering the fact that a steel structure properly designed and worked out in the shop will be 20–40% lighter in weight than a casting for the same purpose, the spread in cost that has existed between certain types of castings and the welded structure has decreased and in some cases passed the equal point.

There are many different problems confronting the iron foundry today. For example, steadily rising costs due to many factors such as dust control, smoke prevention, labor problems and over-all costs. According to May 1938 issue of "Factory Management" labor cost runs from 20 to 25% of the total cost in fabrication shops while in the foundry it runs from 35 to 45% of the total costs. With the present labor trends, this becomes a really important factor. True in the modern mechanized foundry every effort is being made to reduce these costs and above-mentioned troubles. However, almost all efforts along this line increase the overhead seriously. Thus, we have the situation wherein modern trends are working together to make steel structures more and more competitive with cast iron.

### THE PROBLEM OF SPECIAL STRUCTURES

In all kinds of machinery construction, there always exists the problem of special structures.

The cost of making patterns for many large special structures, where only one or two will be required, is prohibitive. The delivery of a steel bed machine will be two to four weeks better than the cast-iron machine. The pattern alone will take as long or longer to build than the welded steel structure and cost as much or more. The cooling in the pit adds about another week to the time required. To put it another way, we have found that the large welded bed can be completed by the time

Fig. 14—Making Last Bend on Main Plate for Large Horizontal Broach

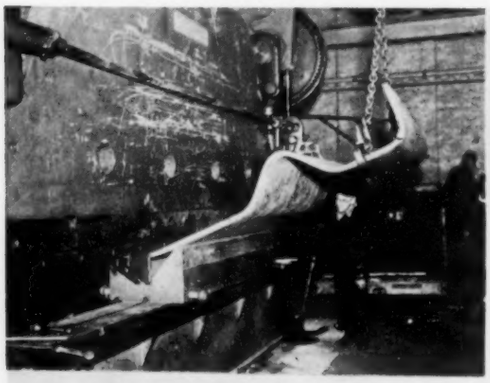
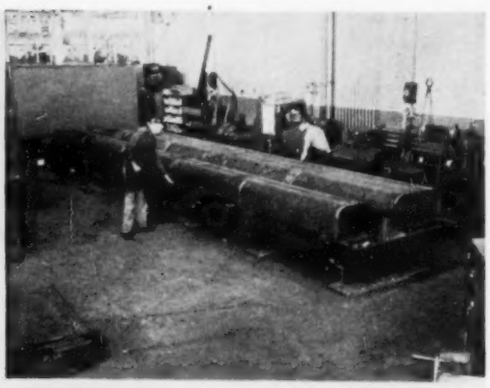


Fig. 15—Lining Up the Main Plates of the Large Horizontal Hydro-Broach



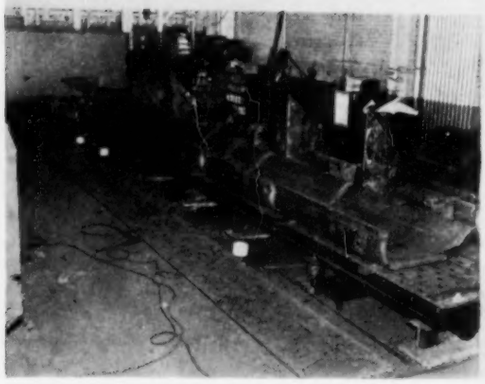


Fig. 16—Upper Set of Ribs Installed on Large Broach

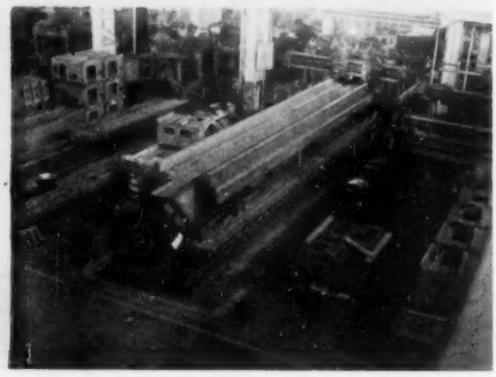


Fig. 17—Machining the Bed of the Large Cylinder Block Broach

the shop can build the important subassemblies. The bed would be in one piece and would be some 20 to 40 per cent lighter than the equivalent casting. The casting would be made in two or more pieces so as to fit into flasks or else it would be a pit job with all the trouble that entails.

When a steel bed is welded we know it is going to be all right the first time. There will be no core shifts, no hard spots or spongy iron. With a large special casting, the problems start when the pattern foreman begins to study the drawing. Quite a bit of engineering shop contact is necessary even before the pattern is made. The foundry superintendent and foreman have to work out the risers, the gating, special vents and the rigging to hold the top down on the pit jobs. After the pattern and cores are made, an excessive amount of supervision is necessary in order to put the mold together. Generally a contact man from the pattern shop is required to help

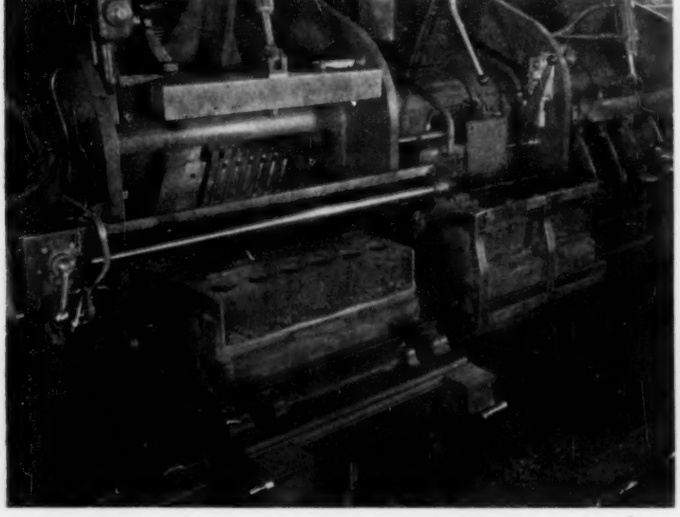


Fig. 18—Fixture in Use on Cylinder Block Broach

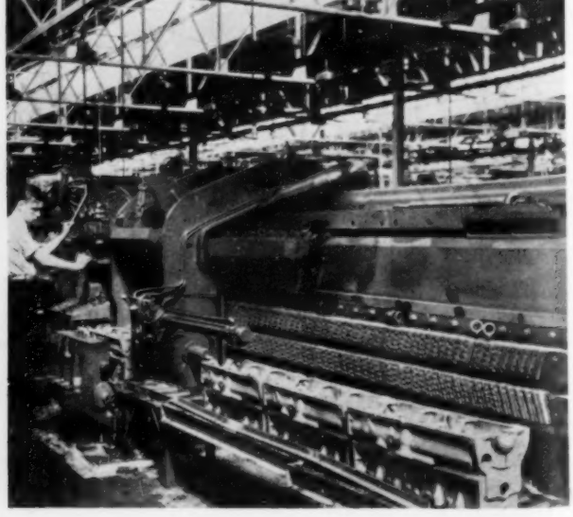


Fig. 19—Complete Cincinnati Horizontal Hydro Broaching Machine Finishing Cylinder Blocks

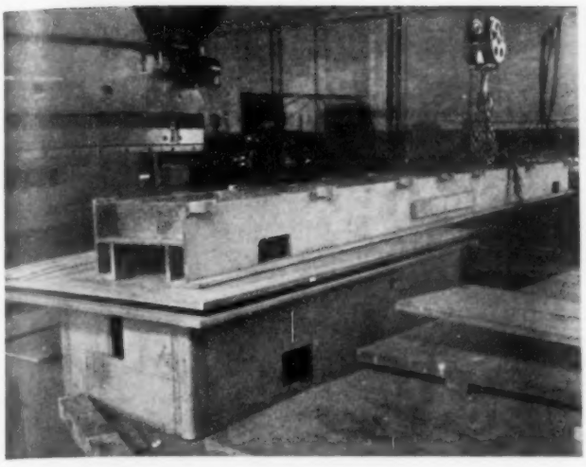


Fig. 20—Welded Horizontal Broach Bed. Illustrating a Simple but Effective Structure

set the cores. After pouring the casting, it is necessary to wait three days to a week for it to cool before digging it out of the pit. With the cores inside, it may be too heavy for the cranes to lift out of the pit. If the casting is bad, nearly two weeks is lost on the delivery.

Naturally the percentage of scrap and rejects on large special castings will be higher than on standard ones. When the cost of the scrap is distributed over the special castings required, the advantage of welding such structures becomes more apparent.

In other words, given the proper machinery and tools which are recognized as the correct equipment for processing the steel, the welding shop will produce machine tool structures which should be welded, at a cost which will be strictly competitive with cast iron. Then, with the cost in line so that the economics of the weld shop justifies a larger percentage of the border line load, a large enough organization will be established so that when special machines that must be made of steel come along, their construction can be completed quickly for the short delivery which is so desirable on special machinery. The cost will then be little more than on standard machines and well below the cost of structures, built with the minimum of equipment.

There is another aspect to this problem which is often overlooked. With a steel structure we have the flexibility of being able to make preliminary tests and minor changes to meet new or unanticipated changes in the part being machined for, or in the machine tool structure itself. Plates, braces, ribs, passages, details of all kinds may be added where they are needed. This flexibility, this freedom in construction, is especially valuable on jobs where there is no time for models or extensive pattern developments. It makes special machinery more economic where standard equipment would do, but is not wanted for any one of many reasons.

In some special cases the problem of anticipating all the conflicts and interferences of the component parts is so difficult that even on standard machines it is good economics to build the first few parts or machines of steel. After the bugs are all ironed out, first class pattern equipment can be built with confidence, knowing that it won't be ruined by changes here and there. While such a condition is not prevalent, it does happen and this approach to the problem certainly expedites the getting into production with the minimum expenditure of time and money.

### DESIGN ADVANTAGES

Knowing steel and cast iron as we do, knowing the advantages and limitations of each, realizing that each must be properly applied if we are to give the customer the best possible machine for his work at reasonable price and at the same time make a profit, we know that the direct result of changing from cast iron to proper design and construction of steel results in either reducing weight or increasing rigidity, whichever the designer chooses—usually he desires both. It should not be overlooked that with steel, the engineer does not have to thicken up a wall here or modify a corner there or compromise in another location, all for casting reasons. He does not have to worry the whole time, as to whether he is going to get a good casting the first or even the second or third trial on some difficult structures. He knows that if some structural problem does develop, the cutting torch or arc welding rod will solve it for him. He knows that the strength and ductility of weld-metal today is such that he can depend on this structure not failing in the welds. Of course, the welding practice, same as the foundry practice, must be right in every sense of the word. The supervision must be trained and with the proper background of good mechanical knowledge. The welder cannot be just the first individual who comes in looking for a job. Many times even good welders must be checked on and guided in their work, to keep the quality of their output the best.

When we take the long range view of the question of welding as applied to machine tools, we realize that there will be opportunities to build machines which will be reasonable in cost and at the same time that will match the performance of equipment built with cast iron. Therefore, the use of welding in future constructions depends largely upon mechanical suitability of the material for a particular application and its ability to equal or get below the cost of cast-iron designs.

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## Welding and Cutting in Machinery Construction

(*Continued from page 30*)

punching and shearing operations on bars, angles, shapes and plates up to $^3/_4$ inch thick by 10 feet wide; on through the forming operations on presses capable of handling plates up to $^3/_4$ inch in thickness and 14 feet in width; through the necessary rolling operations which completes the preparatory work on material prior to assembling. There is then shown the assembly of these prepared parts, in a great many cases including steel castings where economy rules the necessity of using same, on to the welding operations showing all welding being done in position. At this point there is shown films made at a speed of 2400 frames per second of the arc in operation both D.C. and A.C., presenting a rare opportunity to see what actually takes place at the time the weld is made, down the line to the necessary grinding operation for the desired finish, through inspection to the stress-relieving ovens (in color) then shot blasting to remove scale, through the final grinding operations and inspection. The picture moves on to the machine shop showing machine operations of fabricated steel parts without any reduction in cutting or feeding speeds over cast iron due to the proper selection and heat treatment of material used up to and including painting of the finished product.

# MACHINE GAS CUTTING IN A LARGE Steel Foundry*

By W. E. MURRAY† and H. E. HORWOOD‡

FOR some unknown reason the steel foundry has not employed machine gas cutting to the extent it is used by other steel industries. Probably the main reason for this is that the diversified nature of the castings does not lend to quick set-up methods, which are absolutely essential in machine cutting operations. The manufacturers of oxyacetylene cutting machines have ever been ready to experiment but close cooperation from the foundry executives has not always been present, with the result that very little progress in this field has been made.

The largest steel foundry in Canada is operated at Montreal by the Canadian Car & Foundry Co. Ltd. This foundry has a capacity of 4000 tons of miscellaneous steel castings per month, ranging in size from $^1/_2$ pound to 100,000 pounds per casting; in shape from a wing nut to large ball mill housings and turbine runners.

When machine gas cutting was first suggested to the foundry officials some years ago, it was not looked upon favorably. It was thought that owing to the varied shapes of the castings no savings could be effected, as special set-ups would be required for each type of casting. However, in 1937 experimental cuts were made on large risers of about 20 inches in thickness, using a Radiagraph cutting machine. This machine has in all probability been seen or used by most of you gentlemen. It is a small portable machine weighing about 65 lb. Our Fig. 1 illustrates this. It will be noted it has universal movement of the torch, very desirable, as quick adjustment is very often required. This first experiment, although not an outstanding success, did convince those present that machine cutting had a place in the steel foundry if properly applied.

Fig. 2—Roll Housing Casting

It was then decided to make a real test of machine gas cutting with a view of reducing cleaning room costs. The results so far have more than justified our faith in this method of riser cutting, and the cost reduction has been greater than anticipated. Cost reduction on miscellaneous castings is running 25 to 30 per cent on grinding and 30 to 40 per cent on oxygen consumption, with corresponding reduction in labor costs.

It was realized that if progress were to be made, quick set-up methods would have to be found as time saving was a very important factor.

To determine if cutting costs could be reduced by using a Radiagraph in preference to hand torches, our first job was to remove six large heads from a roll housing casting, weighing in the rough approximately 85,000 pounds. Figure 2 illustrates this huge casting. Two of the risers (*B* on sketch) Fig. 3, have been cut and removed. The other four have been cut but left in position for photographing.

Figure 3 gives the dimensions and shapes of the heads. All risers were undercut (excepting those marked *C*) prior to machine cutting. The maximum thickness penetrated by the machine torch was 19 inches. All cutting was done with a three-hose torch, operating in a horizontal position. Casting temperature at commencement of cutting operations was between 600° and 800° F.

It would appear that starting operations on a casting of this nature was like putting the cart before the horse.

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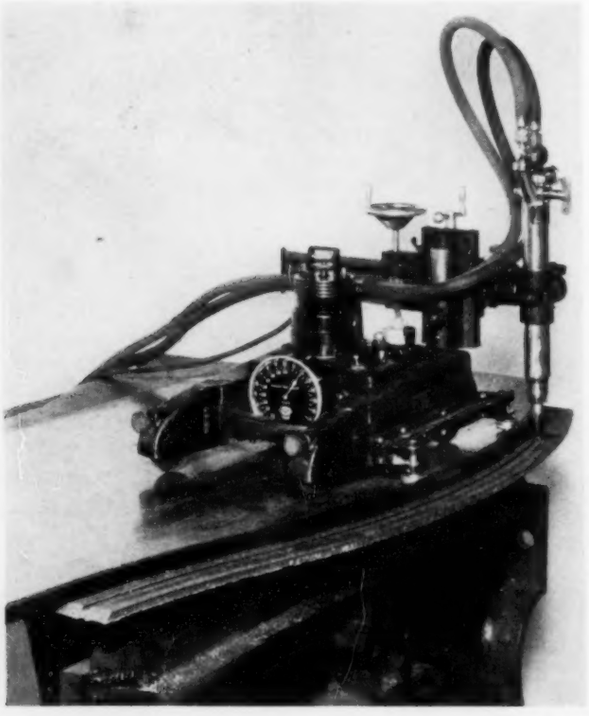


Fig. 1—Making a Curved Cut with Radiograph Using Guide Rollers

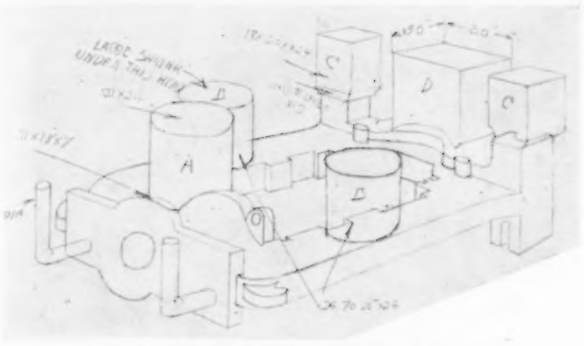


Fig. 3—Roll Housing with Two of Risers Removed

But usually the salesman or promotor of any new process or procedure has such obstacles placed in his way: if they can be overcome, the rest is easy.

**Table 1—Cutting Data—Roll Housing Casting**

| Riser Head | Area Machine Cut | Cutting Time Minutes | Seconds |
|---|---|---|---|
| *A* | 31 in. x 19 in. | 14 | |
| *B*, right | 26 in. x 19 in. | 11 | 47 |
| *B*, left | 26 in. x 19 in. | 20 | (shrink hole) |
| *C*, right | 11 in. x 17 in. | 3 | 33 |
| *C*, left | 11 in. x 17 in. | 6 | 45 (sand) |
| *D* | 30 in. x 19 in. | 10 | |

The total cutting and setting-up time for the six heads was 10 hours.

**Table 2—Gas Consumption—Roll Housing Casting**

| | |
|---|---|
| Cutting oxygen | 2390.4 cubic feet |
| Preheating oxygen | 155.6 " " |
| Total | 2546.0 " " |

Acetylene consumption—not computed.

Cutting operations were performed in late January during severe winter weather. Pressures of oxygen cylinders were down to 1745 pounds per square inch, and our consumptions are based accordingly. On this basis total oxygen consumption was 13.3 cylinders.

Three of these castings were machine gas cut at weekly intervals. The oxygen consumption in each instance was almost identical. However, cutting and setting-up time was reduced to 7 hours.

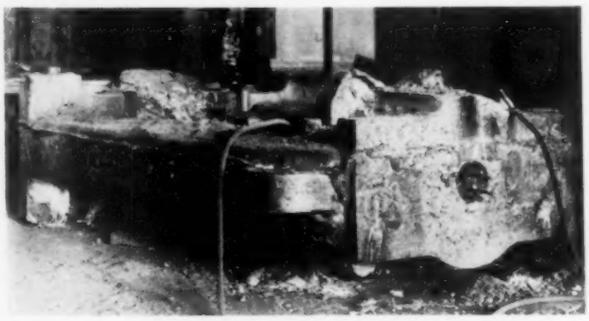


Fig. 4—Roll Housing Casting after Cutting

**Table 3—Machine Cutting Data—Roll Housing Casting**

"*A*"—Gas Saving Effected

| | | |
|---|---|---|
| Total oxygen consumption (machine cutting) | 13.3 cylinders | |
| " " " (hand torch) | 24 " | |
| Saving effected by machine cutting | 10.7 " | =2354 cu. ft. |

"*B*"—Cutting Time Saving Effected

| | |
|---|---|
| Total time (machine cutting) setting-up time included | 7 hours |
| " " (hand " " " " " | 30 " |
| Saving effected by machine cutting | 23 " |

"*C*"—Grinding Time Saving Effected

| | |
|---|---|
| Grinding time (machine cutting) | 9 hours |
| " " (hand torch cutting) | 12 " |
| Saving effected by machine cutting | 3 " |

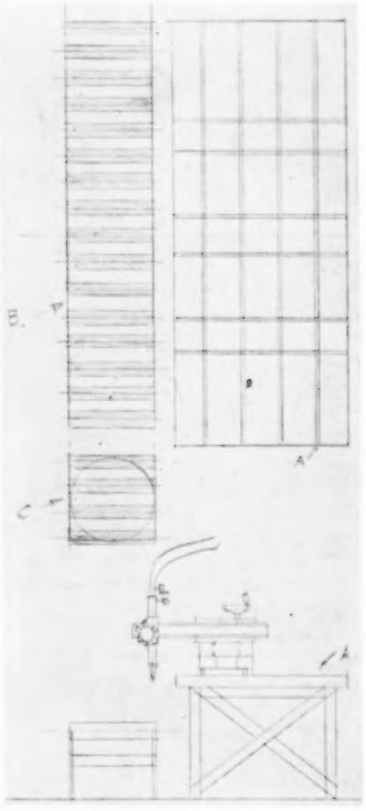


Fig. 5—Set-up for Miscellaneous Castings with Radiograph

**Table 4—Operating Pressures—Roll Housing Casting**

| Gas | Max. Pressure | Min. Pressure |
|---|---|---|
| Cutting oxygen | 140 lb. | 125 lb. |
| Preheating oxygen | 40 lb. | 35 lb. |
| Acetylene | 10 lb. | 8 lb. |

**Table 5—Cutting Speeds—Roll Housing Casting**

Maximum—5 inches per minute
Minimum—1½ " " "

A No. 10 tip (cutting orifice diameter 0.180) was used for cutting riser heads No. 8 tip for riser heads "*C*"—see Table 1.

## EQUIPMENT USED

Radiagraph, operating on 220-volt A.C.

Three-hose cutting torch, employing Nos. 8 and 10 tips.

20-cylinder oxygen manifold with two heavy duty two stage reduction oxygen regulators, operating in parallel.

Two stage reduction oxygen regulator on preheating oxygen cylinder.

3-cylinder acetylene manifold with two stage reduction acetylene regulator.

$^3/_8$-inch hose for cutting oxygen and $^5/_{16}$-inch hose for preheating oxygen, and acetylene gases.

Figure 4 shows the roll housing casting after cutting. The net weight was 53,400 pounds. The cut surfaces have been covered over with sand to retain the heat. The finish of the cut surface was remarkably smooth for the thickness cut.

## SET-UP FOR PRODUCTION MACHINE GAS CUTTING

The results obtained on this housing casting called for immediate consideration of employing the Radiagraph for riser cutting wherever possible.

Orders had been received at the foundry for all the steel castings for 2000 freight cars, which demanded

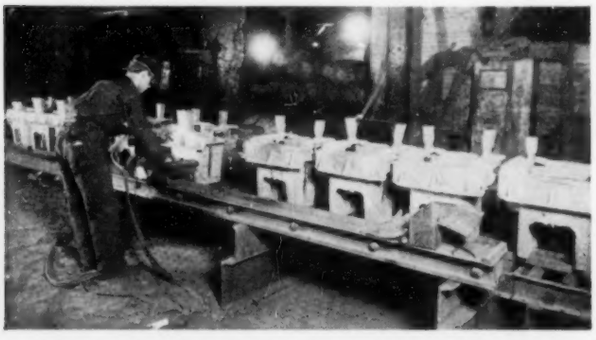


Fig. 6—Striking Plate Castings on Conveyor Line for Machine Cutting

production methods. The management worked out many time-saving set-ups. After several discussions it was decided to use conveyors to bring the castings to the machine, and thus keep it operating continuously, and eliminating adjustments for each casting.

The main set-up for production cutting of miscellaneous castings is as shown in sketch, Fig. 5. This set-up requires a runway table, *A*, for the Radiagraph, which has grooves machined in the runway in several positions running lengthwise and crosswise. In front of the runway is roller conveyor, *B*, also turntable, *C*, which is equipped with roller conveyor. With this arrangement it is possible to cut vertically and horizontally, also lengthwise and crosswise of the casting. Where it is required to cut on the casting beyond reach of the torch, the casting is rolled back, turntable reversed, bringing the cut within the reach of the Radiagraph.

It will be noted from this set-up that a great many combinations can be obtained, and the operation of the machine can be made without lost time, thereby speeding up production. This set-up is particularly applicable to miscellaneous steel foundry work.

Figure 6 illustrates striking plate castings on the conveyor line. This set-up is used for cutting riser heads from center brace, striking plates, draft gear cylinders, draft gear shoes, draft gear wedges and Cardwell draft gear castings.

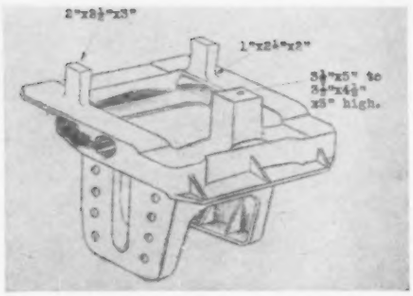



Fig. 7—Sketch Showing Dimensions of Striker Plate Casting

In removing riser heads from the castings enumerated (excepting shoes and wedges) two machines are employed and a four-man crew. The conveyor line is served by two jib cranes, one used in feeding the conveyor, the other in removing the finished castings. Cutting is done from both sides of the conveyor line simultaneously. The two helpers operate the cranes and spot the castings. It will be noted from our illustration that the castings are placed on plates to facilitate movement on conveyors and to speed up spotting of castings for cutting.

A sketch of a striker plate casting with dimensions and locations of heads is shown in Fig. 7, and one of the center brace casting with dimensions and location of heads in Fig. 8.

Fig. 9 shows Cardwell draft gear housing castings on the production line. A homemade machine is illustrated but this set-up is not now employed, as these castings are also run through on the set-up shown in Fig. 6. Fig 10 is a sketch of a Miner Draft Gear cylinder castings. In Fig. 11 are shown Miner draft gear shoes on the production cutting conveyor. Note the type of jig employed for holding these small castings. This same jig is also employed for holding the draft gear wedge. Sketches of the draft gear shoe and wedge castings giving dimensions of the riser heads appear in Fig. 12.

**Table 6—Production Records**

| Casting | Quantity | Total Heads | Sq. Ins. Total Cut |
|---|---|---|---|
| Center brace | 64 | 256 | 2048 |
| Draft gear cylinders | 216 | 648 | 3780 |
| Striking plate | 101 | 303 | 2273 |
| Totals | 381 | 1207 | 8101 |

The total number of castings in Table 6 were cut in eleven hours, by two operators and two helpers.

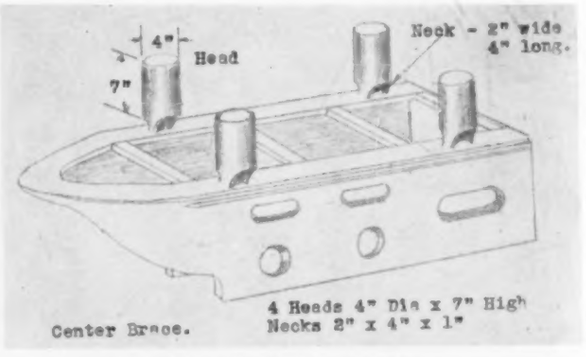



Fig. 8—Center Brace Casting

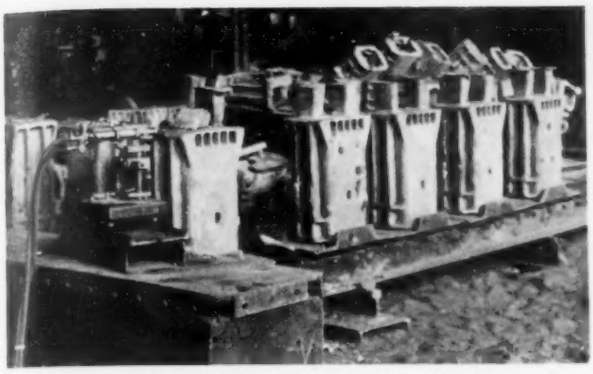


Fig. 9—Cardwell Draft Gear Housing Casting on Production Line

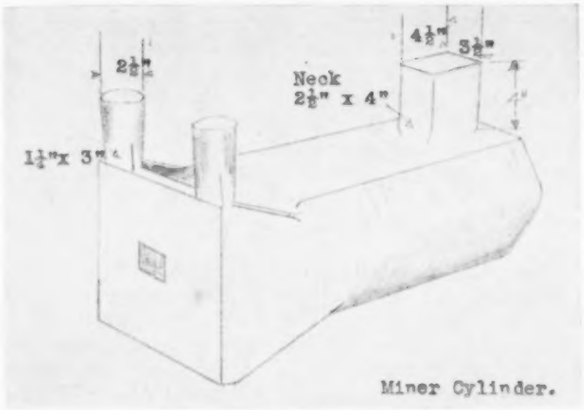



Fig. 10—Miner Draft Gear Cylinder

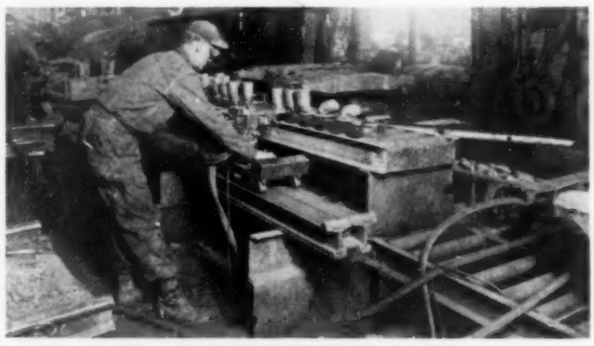


Fig. 11—Miner Draft Gear Shoes on Production Conveyor

Production on draft gear shoes, Fig. 11, is at the rate of 115 per hour, and on the draft gear wedges, 60 per hour; two-man crew, operator and helper.

Cardwell draft gear housings, Fig. 9 are cut at the rate of 43 castings (86 heads) in forty-four minutes; two operators and two helpers being employed.

All production figures are authentic, having been carefully checked by the chief checker of the foundry.

A heavy preheat tip size No. 4 is used for the castings mentioned, at the following oxygen pressures; Draft gear cylinders, 55 pounds; striker plate castings, 70 pounds; and center brace castings, 60 pounds. The acetylene pressures were 4 pounds in each instance.

Fig. 13 shows a sketch of a driving-box casting. The pads are removed with the Radiagraph so smoothly and accurately that grinding has been eliminated and chipping is now only a minor operation. The back of the pad is undercut with a hand torch as indicated at "*A*," to prevent gouging due to thinness of metal at this point. The castings are cut at the rate of three per hour (six pads). Oxygen pressure 120 pounds and Acetylene, 5 pounds.

Machine gas cutting of heads and pads from gears presented a problem but due to the ingenuity of the foreman in the cleaning room, a turntable was designed and built to handle gears from 12 to 72 inches in diameter. Figure 14 shows clearly the design of the turntable and the procedure employed in spotting it on the work table for the various sizes of gears. The Radiagraph is mounted on the operating table, and the radius rod is employed as indicated. When one head is removed, the turntable is easily and quickly revolved to place the next head in line for cutting. By this method the Radiagraph only travels the length of the head being cut and is then free-wheeled back to start the next cut. Details of the procedure follow:

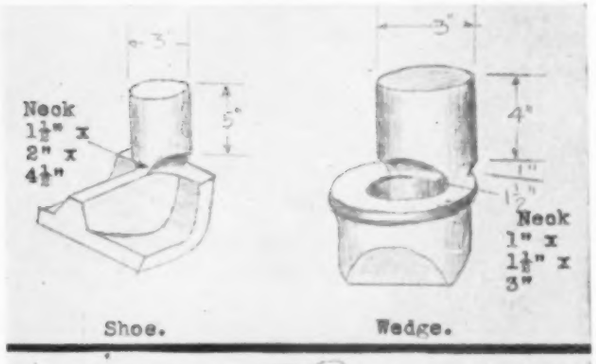
The gear casting "*A*" is mounted on spacers "*B*" which are in turn mounted on turntable "*C*". The purpose of the turntable is to revolve the gear casting "*A*" to bring the several pads in line with the torch. A center-pin "*D*" is securely fastened to operating table "*E*," and the center-pin is provided with a center upon which the radius rod "*F*" revolves. Wheel "*G*" only rides on the table "*H*" as is standard practice for circle cutting.

Table "*E*" is provided with a series of holes "*J*" into which the center-pin "*D*" is fastened and the location of these holes "*J*" are so arranged as to accommodate the various diameters of gears to be cut. This whole set-up is installed on a cement floor, and the operating tables "*E*" and "*H*" are accurately leveled.

When heavy cuts are made and it is found necessary to raise the torch beyond machine capacity, rails are laid on table "*H*" over which a ½-inch plate is placed to provide a runway for the Radiagraph. With this set-up it is possible to make a very close cut, reducing grinding costs 40 to 50 per cent. The cutting of risers and pads from gears is a one-man operation.

Our only problem now is the removing of the center

Fig. 12—Draft Gear Shoe and Wedge



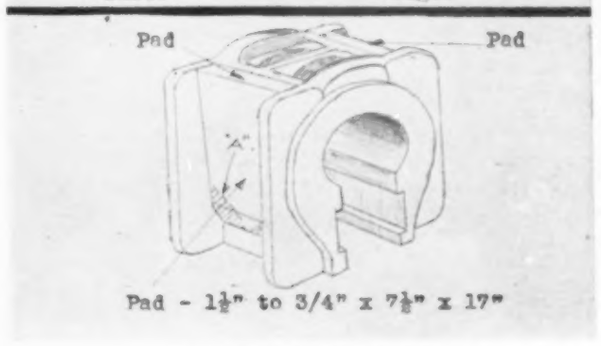




Fig. 13—Drawing-Box Casting

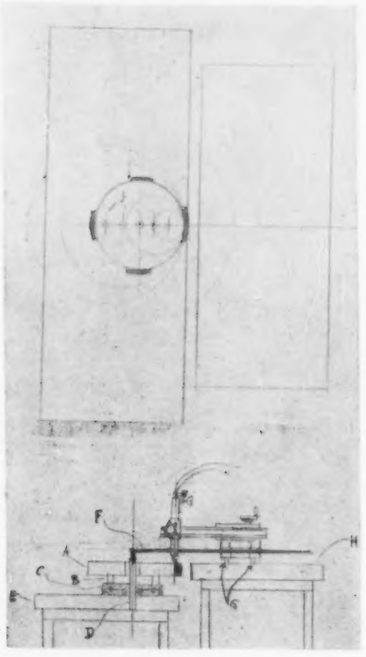


Fig. 14—Set-up for Cutting Pads from Gear Rims with Radiograph

Fig. 15—Main Operating Station

head riser from gears. These heads are usually cored, and generally have to be cut by a hand torch as they must be cut flush with the gear hub. The hub is usually recessed below the rim. We are working out a precedure for this operation, and we believe the solution is to use a special long bent torch, and probably a bent tip as well. The turntable for this operation will be mechanically operated by means of a worm drive.

Tips 7 inches long are used in removing the risers from the gears to permit them being cut as flush to the casting as possible.

Fig. 15 is a picture of the main operating station. It shows riser heads being removed from a locomotive cylinder head casting on turntable. This operating station is also served by a jib crane and air-hoist. The twenty cylinder manifold is used only when cutting large heads but generally torches are operated off the oxygen and acetylene lines.

It is contemplated that 50 per cent of the general run of castings will in future be machine gas cut. Many other time saving jigs and fixtures will be worked out. A contemplated change is having the main operating table mounted on hydraulic jacks to speed up raising and lowering, when switching from small to large castings and vice versa.

# AUTOMOBILE BODY WELDING*

By EARL H. FOSS†

THE last fifteen years have provided us with a transition from wood to steel body structure. In the early days, as steel began to creep into the picture, welding was far removed from a science and was regarded merely as a means to an end. No thought was given to the technique of the welding operator and less thought was given to process methods and equipment. As it became apparent that a steel body was the most suitable with which to equip an automobile, it also became apparent that a sturdy, rapid means of fabrication was necessary. The realization of this caused the birth of welding as a science in the automobile industry. Manufacturers of welding equipment and supplies appropriated time and money for research, and individuals labored hard and long to perfect methods of fusing together separate parts of sheet metal into a single unit. It is through their efforts that welding as a science holds a position of supreme eminence in the body industry of today.

Although we take the liberty of admitting that present body welding is a pretty high class piece of work, we should by no means feel that we have reached the ultimate. New sizes of sheets from the steel mills, new structural details off the boards of the designer, new demands of a critical public and the ever present slogan of engineering "do it better at lower cost" demand new welding processes as well as better procedures for old methods.

Without welding developed as a science, it is doubtful if mass production could be accomplished. Without the aid of welding, the body designer would not be able to give us the present body with its full flowing lines and rounded contours. Without welding, the public would not have the advantages of a rigid body combining comfort, safety and beauty.

While the rapid advancement of welding technique has made possible the all-steel body, the likewise rapid progress of welding control has assured success in quantity production. We do not propose to minimize the importance of the welding operator—a good operator is essential to any job. However, in both theory and practice it has been proved that greater economy, speed and uniformity of product can be obtained through control of as many variables as possible by the welding engineer.

If it were not for accurate control, electrical resistance welding, which plays a major part in present-day body fabrication, would provide numerous headaches for the designer and welding engineer, as well as the public who ride so safely and comfortably in the body of today. Two types of resistance welding are generally used, namely, butt welding and spot welding. In the body business butt welding consists of holding two steel sheets in a

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device that is both a welder and a jig which presses these pieces together while heat is generated by a high electric current passed through the area of contact. This type of weld would lack uniformity and limit a high rate of production if it were not for well-developed regulatory features that synchronize as well as control the current and the successive pressures that are applied. Spot welding has proved to be a great boon to the production engineer. This apparatus consists of a transformer, a ready supply of air pressure and copper alloy electrodes, and is so designed that it will weld at the rate of eighty to one hundred and fifty spots per minute. The transformer furnishes a high current at low voltage to two electrodes which are brought together on a lap seam of two or more sheets by air pressure. Accurate relays, switches, valves, etc. control the time cycle so that the proper amount of current is kept on the proper length of time at the right air pressure. Through absolute control of timing, current and pressure in resistance welding, the engineer can be assured of greater electrode life, good quality in welds, minimum surface oxidation, less surface deformation, wider application to alloy welding and speeding up of production. We have another form of welding in our shop that is a modified type of spot welding which we popularly call "indirect welding." This is used on the door panel and permits us to weld the inner panel to the outer door without marring the surface.

We have found it profitable to employ a butt welder for salvage work. Small pieces of scrap steel which were formerly sent to the baler are now salvaged by flash welding and used for pillar reinforcement brackets and trim sticks.

As in all present day manufacturing, the oxyacetylene process adapts itself very well to the automobile body industry. Whenever we think of large quantities of instantaneous heat, we think of the blowpipe whose flame develops temperatures as high as 6300° F. With recent developments manufacturers of oxygen and acetylene have given the industry many new features in control and distribution of gases. Time, space and expense are no longer lost through handling cylinders on the production floor. The present body plant has central distribution points for both oxygen and acetylene. The gases are delivered through pipe-lines to welding outlets at accurately controlled pressures. An oxyacetylene installation of this type permits us to use the gas as easily as we use water, electricity or air. This system not only permits greater economy and safety but also allows the welding engineer to maintain close control over a large group of operators.

The public, who have taken so kindly to the automobile, regard the body entirely in the aggregate. It is an object of some beauty, is sturdy and comfortable and furnishes ample protection from the wind, the rain and the cold. However, the body and welding engineers see an automobile body as a complex object of many individual parts, each part presenting a separate problem in design and fabrication.

The completed steel body is composed of several subassemblies, each being taken care of as an individual product until all subassemblies meet on the final line at which point the body begins to take form. Fenders and motor hoods are manufactured as quite separate units (often being manufactured in outside plants) and are placed on the body only after all the other work has been completed. The finished body has about five thousand welds.

It may be of interest to point out the precautions taken with the metal parts before they reach the subassemblies. The surfaces are protected with either a soap solution or graphite powder during progress through the press line, thereby assuring us of surfaces which will require a minimum of metal finishing.

The roof assembly consists of a drip moulding, the windshield frame, the rear window frame, ventilator lid and dome light bracket as well as the large single sheet that is pressed out to form the roof itself. A total of fourteen parts are incorporated into this assembly requiring three hundred and twenty resistance welds and two oxyacetylene welds.

Adaptation of an all-steel roof to body construction has simplified many problems connected with the side assemblies. Thirty parts ranging from the small clips on the window frame and wheel housing to the rear quarter panel pass through the hands of the welder on the way to the side assembly jigs. With precision gages and air controlled clamps the parts are held in place and fused into a single unit with a total of two hundred and eighty welds.

The front end assembly which is composed of forty-three pieces is recognized in the industry as the unit that takes more stresses and strains than any other. More than four hundred resistance welds are required in fabrication, these being supplemented by oxyacetylene and arc welds at the toe board riser and front pillar. Periodically the welded unit is placed on a surface plate to check for alignment, and on the racking machine to test the quality of welds.

We are all aware of the fact that in early body construction most squeaks emanated from the doors. Improvement in both design and welding has gone a long way in reducing these disagreeable noises in the body of today. A total of fourteen parts comprising inner and outer panels, regulator panels, cover brackets and many reinforcements and strainers take one hundred and fifteen welds to make the door of sound construction. The window flanges are bronze-welded and the hinges are riveted and arc tacked into place.

The underbody assembly is made up of three main sheets heavily ribbed in the stamping operation to give rigidity. One hundred and nineteen welds are needed to form fifteen parts into a single piece.

The final assembly is effected in a large "buck." Here the subassemblies are united by welding after they have been located and securely clamped. At this point in the construction of the body oxyacetylene welds and arc welds are used quite extensively to secure the underbody and the door posts, as well as some of the heavier reinforcements. As the body advances down the line many smaller parts are added such as gussets, header reinforcements, tail panels, etc. For this, the small gun type spot welders are used.

We have observed that a gun welder is used about twenty-five per cent of the total job time; seventy-five per cent of the time being used for loading and unloading fixtures and locating and clamping the panel where fixtures are not used. As a result of this, we find it advantageous to perform different operations in sequence and use multiple gun units as much as possible. This facilitates production and saves cost of separate transformers, contactors and timers for each gun.

When the body leaves the final assembly line, all welding has been completed and the welding engineer is through with that particular unit. The metal surfaces are finished and the body is washed and sent to the paint shop.

A paper on body welding would seem incomplete without some mention of the importance of jigs and fixtures. If we did not have benefit of accurate means of lining up the individual parts for welding and holding these parts during welding, I shudder to think what shape a body would take upon completion. Jigs and fixtures are a necessity placed on welding by today's standard of production.

# SILVER ALLOY BRAZING OF TUBES in High-Pressure Boilers*

By A. W. WEIR† and H. M. WEBBER‡

VERTICAL fire tube type boilers installed on passenger-electric locomotives to furnish steam heat and hot water for trains operating over electrified zones of the New York Central System are equipped with copper tubes mechanically expanded into steel heads. Figure 1 shows a typical construction. Copper has been chosen as the material for the tubes because of its high thermal conductivity and resistance to corrosion, and the heads are made of 3/4-inch steel for strength. A number of different methods have been developed for fastening the tubes to the heads; the one employed at present consists of expanding the ends of the tubes, beading and installing ferrules. The boiler is oil fired, with the products of combustion traveling up through the tubes and with water and steam surrounding the tubes. A stack at the top exhausts the products of combustion. This type of boiler is capable of starting with cold water and building up to a steam pressure of 225 pounds per square inch within six minutes. Other performance data, and specifications, are as follows:

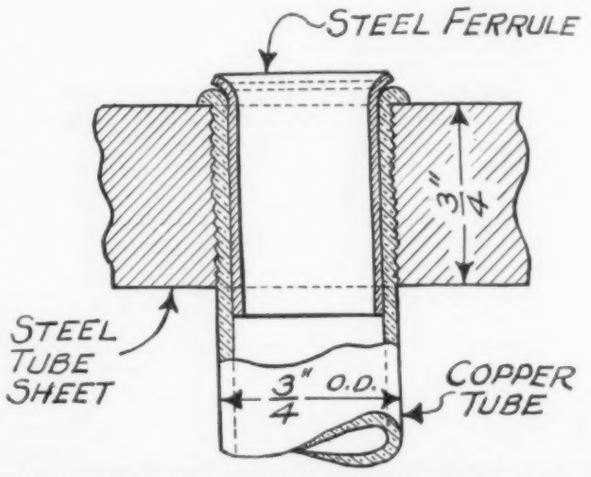


Fig. 1—Present Construction of Mechanically Joined Boiler Showing the Copper Tubes Expanded, Beaded and Ferruled in Steel Tube Sheets. These Mechanical Joints Work Loose in Service Causing Leaks Which Result in High Maintenance Expense

### BOILER PERFORMANCE DATA

Evaporation (by test)—6800 lb. per hour
Safe working pressure—225 lb. per square inch
Firebox heat release—368,000 B.t.u. per cu. ft. per hour
Firebox temperatures—2600 to 3000° F.

### TUBE SHEETS

Diameter—48 inches
Thickness—3/4 inch
Material—Boiler Steel N. Y. C. System Spec. 1002

*Chemical Composition*

| | | | |
|---|---|---|---|
| Carbon | | 0.12–0.25 | per cent |
| Manganese | | 0.30–0.50 | per cent |
| Sulphur not over | | 0.04 | per cent |
| Phos. | Acid not over | 0.04 | per cent |
| | Basic not over | 0.035 | per cent |

### TUBES

Thickness—No. 18 Stubs' gage (0.049 inch)
Outside diameter—3/4 inch
Length—35 3/4 inches
Material—Phosphorous-deoxidized copper
Number of tubes—1237

### OBJECTIONS TO PRESENT CONSTRUCTION

Since the copper tubes are mechanically fastened into the steel heads of the boiler, the difference between the coefficients of expansion of the copper tubes and the boiler shell results in the introduction of stresses under heat. When the joints are tight, these stresses are taken up by a slight buckling of the tubes, but repeated heating and cooling of the assembly and vibration of the locomotive eventually cause some of the tubes to work loose in their joints. No mechanical joints have been produced to date to completely overcome this difficulty.

Obviously the leakage of a number of joints necessitates taking the locomotive out of service so that the boiler can be removed from the locomotive and the joints expanded tight. This maintenance is costly and loss of service of the locomotive is a handicap and expense. After 48 months of calender service the 1237 copper tubes in the boiler, although in excellent condition, must be drilled out and consigned to the scrap heap because of destruction of their ends in removal by the drilling out operation.

### METHODS OF OVERCOMING THE DIFFICULTIES

Obviously if a method could be found for bonding the tubes to the heads, such as by welding or brazing, it would be impossible for the tubes to slip in the joints and cause leaks, and this should result in greatly extending the life of the boiler with practically no shut downs or time out of service for repairs. Extensive experiments have been conducted on welding the copper tubes to the steel heads using several methods, but the results have been far short of the standards of perfection desired. The failures to do the job by welding suggested the possibility of brazing the joints with a silver brazing alloy. Since there were 2474 joints in the assembly, the

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Fig. 2—Photomicrograph of a Section of Copper Tubing Near the Outside Surface Showing Embrittlement of the Outer Portion Due to Treatment in a Slightly Reducing Atmosphere. The Tiny Circles Indicate Steam Pockets in the Copper. 200 X

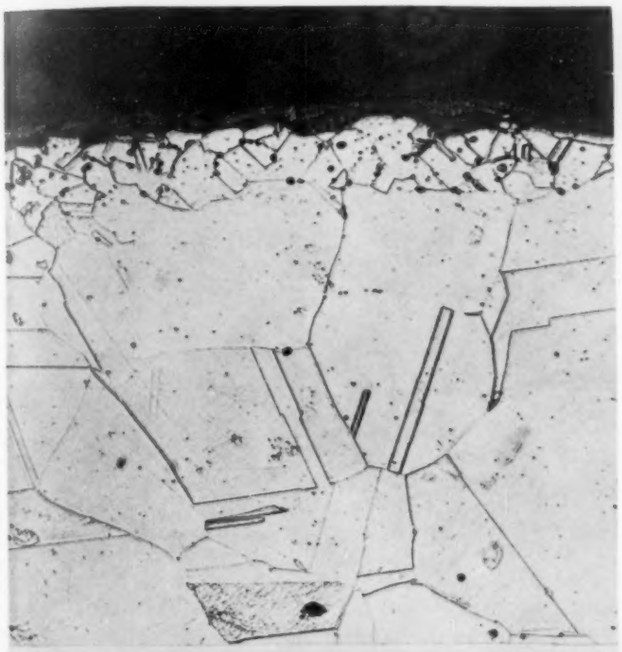
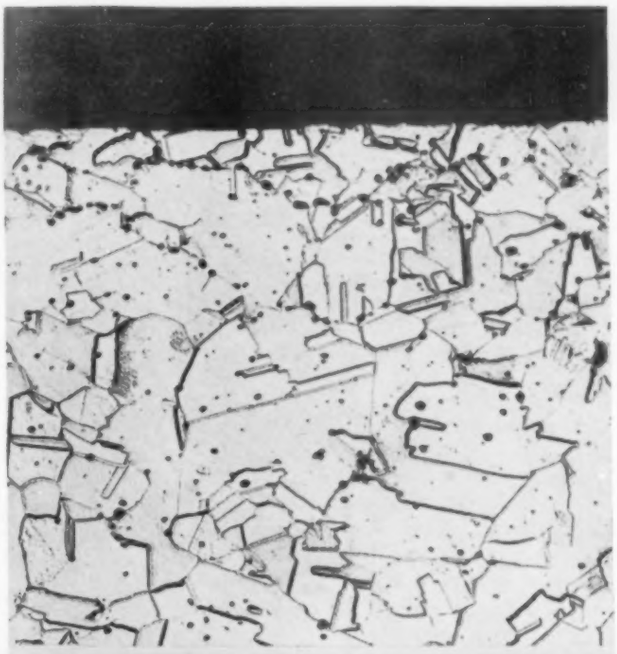


Fig. 3—Photomicrograph of a Section of Tough-Pitch Copper Given the Same Treatment as the Tube Shown in Fig. 2. Note Embrittlement Throughout. 200 X



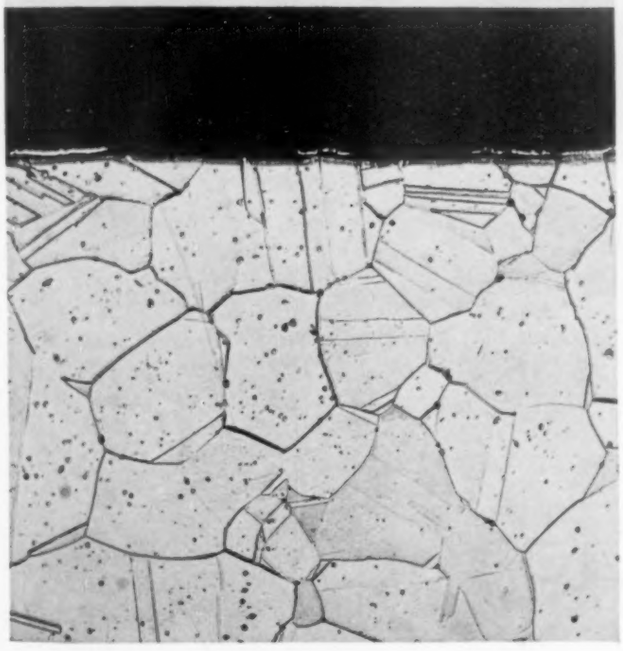


Fig. 4—Section Through Tough-Pitch Copper Treated in Slightly Oxidizing Atmosphere Showing No Embrittlement. The Small Circles Are Oxide Particles. 200 X

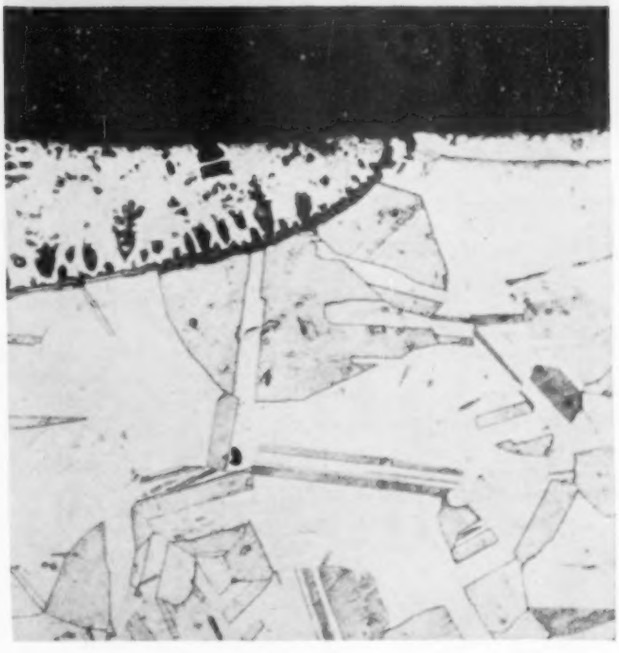


Fig. 5—Only Slight Penetration (0.004 In.) of Silver-Brazing Alloy Into the Outer Surface of the Copper Tube Is Indicated in This Photomicrograph. The Sample Was Treated for 1 Hour at 1285° F. in a Slightly Oxidizing Atmosphere. 200 X

possibility of brazing them all at one time in an electric furnace looked attractive. Therefore, it was decided to investigate the furnace brazing method.

## METALLURGICAL CONSIDERATIONS

Before proceeding to furnace braze a large tube bundle, a study was made of the possible effects of time, temperature and furnace atmosphere. It was known that the tubes available were made of copper which had been deoxidized with phosphorus in its manufacture and that there is no assurance that the deoxidation is always complete in this process. Experience, therefore, dictated that the protective atmosphere should contain no hydrogen or carbon monoxide because hydrogen will combine with oxygen in the copper and cause embrittlement at temperatures in excess of 750° F., and carbon monoxide will produce a similar effect. The combining of hydrogen and oxygen forms steam pockets within the copper, which build up tremendous pressure and actually blow the copper apart.

If the copper tube should become embrittled through-

Fig. 6—A Large Tube Bundle Having 1237 Copper Tubes Mounted in Steel Tube Sheets, Prepared for Furnace Brazing, Is Shown Here Set Up on a Pedestal on the Furnace Base. The Sheet Alloy Retort at the Right Was Placed Over the Charge and Then the Furnace Was Lowered Over This Retort. The Protective Atmosphere Was Maintained Within the Retort Throughout the Entire Cycle. The Furnace Covered the Retort Only During the Heating Cycle

out, it would be subject to fatigue failure. Even if it should be embrittled only on the outer surface, cracks would likely start from vibration and in addition the brazed joints would be weak because the brazing alloy would adhere only to the weakened layer of embrittled copper which might ultimately be pulled apart from the solid body of the tube. This would ultimately develop leaks.

It was decided to make a number of preliminary tests on small samples first in a quartz-tube furnace, then in a box-type furnace. Two gas mixtures for furnace atmosphere were available from gas supplies used in an installation of furnaces for bright annealing copper wire at low temperatures. A third mixture was obtainable by making miner adjustments at the source of one of the others.

These were as follows:

| Constituents in Gas Mixture | Gas Mixture Number, and Percentages of Constituents | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| $CO_2$ | 10.6 | 0 | 10.6 |
| $O_2$ | 0 | 0.2–0.4 | 0.2 |
| CO | 0.2 | 0 | 0 |
| $H_2$ | 0.3 | 0 | 0 |
| $N_2$ | 88.9 | 99.8–99.6 | 89.2 |
| | 100.0 | 100.0 | 100.0 |

It will be noted that the first mixture contained fractions of a per cent of hydrogen and carbon monoxide, which were viewed with suspicion. However, since this mixture was emanating from a combustion type furnace-atmosphere controller, it was a simple matter to eliminate the hydrogen and carbon monoxide if necessary, and swing over to a slightly oxidizing gas as indicated in the third column, by increasing the ratio of air to coke-oven gas entering the burner of the atmosphere controller. The second and third gases, then, were almost inert, but leaned toward the oxidizing side. All three gases were used in the preliminary furnace-brazing tests.

It was desired to keep the furnace temperature as low as possible for a number of reasons and, therefore, a brazing alloy was selected which melts at 1175° F. and generally requires a furnace temperature of 1225–1400° F. This alloy consists of 50% silver, 15.5% copper, 16.5% zinc and 18% cadmium and is called "Easy-Flo."

A number of individual samples were made up for tests, consisting of copper tubes to be brazed to steel, and pieces of tough-pitch copper known to contain oxygen, to be treated along with these brazing samples for comparative purposes so as to observe the effects of the atmosphere. The samples were left in the furnace for various periods at temperatures ranging from 1225 to 1285° F. Although the pieces of steel were unaffected by the treatments, examination of the copper samples for embrittlement when treated in the three different gases as described above showed the following results:

| Gas No. | Effects on Copper Tubes | Effects on Tough-Pitch Copper |
|---|---|---|
| 1 | Embrittlement on outer surface only (See Fig. 2) | Embrittlement throughout (See Fig. 3) |
| 2 | No embrittlement (See Fig. 4) | No embrittlement |
| 3 | No embrittlement | No embrittlement |

With gas No. 1 it was found, as indicated, that the copper tube was embrittled only on the outer surface which was taken as an indication of oxidation during hot-working operations on the tubes. This embrittlement is indicated in Fig. 2 by black spots which are the steam pockets embedded within the copper. Such surface embrittlement would not be permissible, as previously explained. Further evidence that gas No. 1 is sufficiently reducing to cause trouble is shown by the embrittlement throughout the tough-pitch copper as indicated in the photo-micrograph Fig. 3. Such would be the effect on any of the tubes which might not be oxygen free. With these indications gas No. 1 was ruled out and it was decided that only the slightly oxidizing gases Nos. 2 and 3 were eligible. No embrittlement was found in either the copper tube or the tough-pitch copper using the latter gases. The photo-micrograph Fig. 4 is typical of the solid structure of the copper obtained in these gases.

A factor influencing the choice of "Easy-Flo" with its low-melting point was that at elevated temperatures silver-brazing alloys have such great capacity for dis-

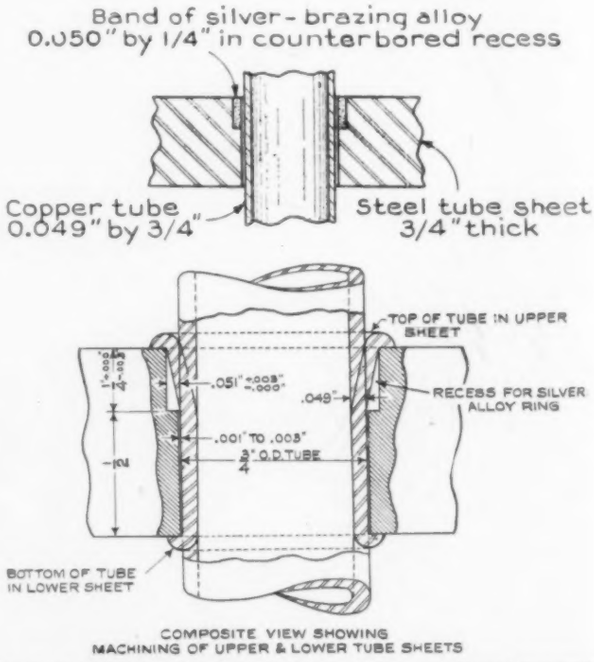



Fig. 7—Cross Section of a Typical Joint in the Furnace-Brazed Assembly, Showing a Counterbored Recess to Hold a Band of Silver-Brazing Alloy

solving copper that there is danger of the brazing metal actually chewing its way through thin copper walls which in this case would result in destruction of the tubes if allowed sufficient time at high temperature. With $^3/_4$ inch thick steel tube sheets and the relatively light weight 0.049 inch thick copper tubes, it would be quite impractical to furnace braze a large tube bundle with high melting alloys because of the accelerated rate of solution at the high temperature and the relatively long time cycle required to heat the heavy mass.

Another influencing factor was that with the slightly oxidizing atmosphere chosen, it became necessary that the flux carry the entire burden of preventing oxidation at the joint and assuring wetting of the silver-brazing alloy on both the copper and the steel. The long time required to heat the large tube bundle made it advisable to keep the temperature as low as possible in order to avoid rapid exhaustion of the flux.

The preliminary tests indicated that with samples held at 1285° F. for as long as one hour very little penetration of the silver brazing alloy into the copper took place. Thus, the danger of brazing alloy chewing into the tubes in the large tube bundle could be almost forgotten. Figure 5 is a photo-micrograph taken of one of the samples treated as described, where a drop of silver brazing alloy clung to the surface of the copper tube beneath a joint. It shows the small amount of penetration of the alloy into the copper. This same series of tests showed that the flux which was used on the samples remained active throughout the heating cycle and it was felt that it would be suitable for the large tube bundle.

A remaining consideration of importance prior to furnace brazing the large tube bundle was that of temperature control. It was agreed that very uniform temperature was necessary and that overheating of localized portions of the tube bundle should be avoided. Also the time throughout the brazing cycle should be as short as possible, particularly above the melting point of the brazing alloy. A bell type furnace rated at 104 k.w., Fig. 6, which was available was known to have excellent temperature distribution because of: (1) proper graduation of heat on the side walls from the bottom to the top, (2) two zones of heat in the height of the furnace, (3) automatic temperature and power control, and (4) a high-volume fan in the base to circulate the furnace-atmosphere gas. The furnace was of ample size to accommodate the large tube bundle, having loading dimensions of 50 inches diameter x 60 inches high.

It was decided to use this furnace for the large tube bundle but to first make a trial run on a small tube bundle consisting of only seven tubes of full length of $35^3/_4$ inches pressed into 6 inch diameter steel tube sheets of regulation thickness of $^3/_4$ inch. Figure 7 shows a cross section of the type of joints used, and indicates counterboring to provide a recess for the band of silver-brazing alloy. This assured that the brazing metal would be in place when it melted and would have no opportunity to run away from the joint. In other words, a reservoir was provided to assist the brazing metal in running into the joint. At this point a procedure was established for cleaning the parts so as to assure best possible results. This procedure was followed in the preparation of the seven-tube bundle as well as for the subsequent 1237 tube bundle. It is as follows:

*Procedure for Cleaning and Preparing Assembly*

1. Cleaning. Mechanically or chemically remove all dirt, oil, scale and oxides from the bored openings in the tube sheets. The copper tubes should be completely cleaned by bright dipping in the following solution:

Dissolve $5^1/_2$ pounds sodium dichromate in 10 gallons of water, then add $1^1/_2$ gallons oil of vitriol spec. gravity 1.84. Remove all oxides. Temperature of the bath should be between 150° and 180° F.

NOTE: Only a lead lined tank should be used for the solution and the deposit which forms on the lead lining should be allowed to remain as it acts as a protection for the lead itself and will greatly lengthen the life of the lining.

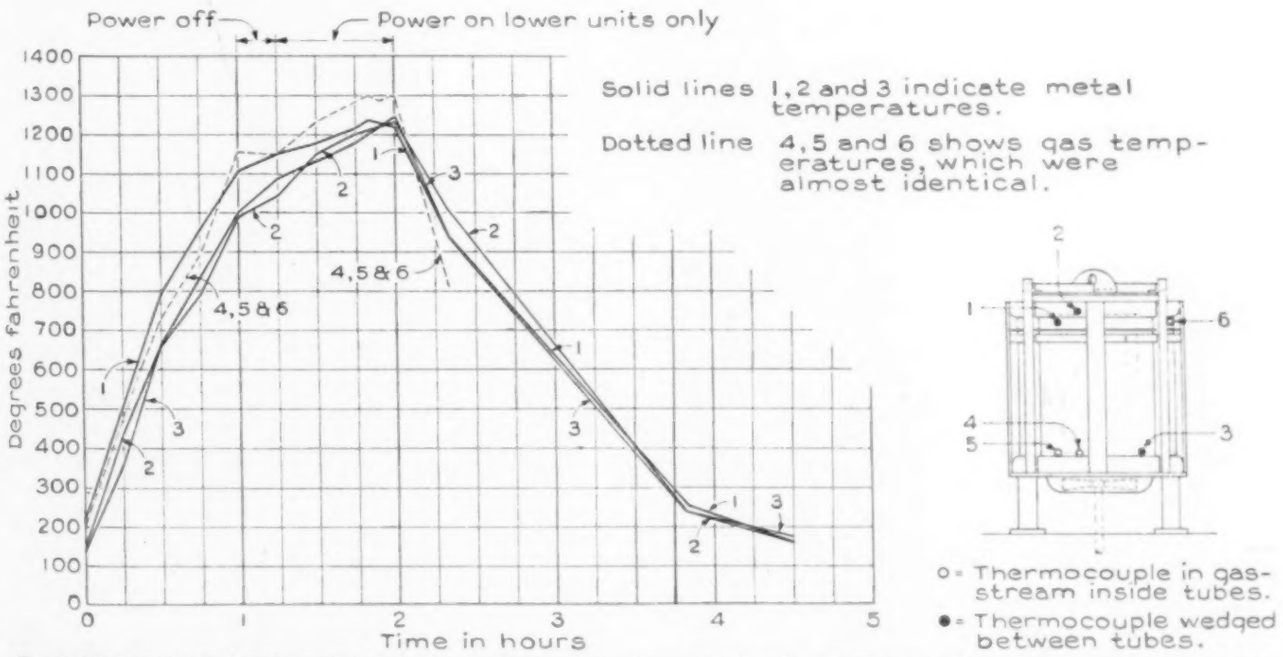

Power off
Power on lower units only
Solid lines 1, 2 and 3 indicate metal temperatures.
Dotted line 4, 5 and 6 shows gas temperatures, which were almost identical.
Degrees fahrenheit
Time in hours
4,5&6
o = Thermocouple in gas-stream inside tubes.
● = Thermocouple wedged between tubes.

Fig. 8—Heating and Cooling Curves Taken During the Brazing of the Large Tube Bundle. Note That the Maximum Temperature Differential Throughout the Charge at the Highest Point Is Only +9° F. The Solid Lines Indicate Temperatures of the Copper Tubes at Different Points in the Assembly. The Dotted Line Indicates the Temperature of the Gas at Three Different Points, the Curves Being So Close Together That They Coincide

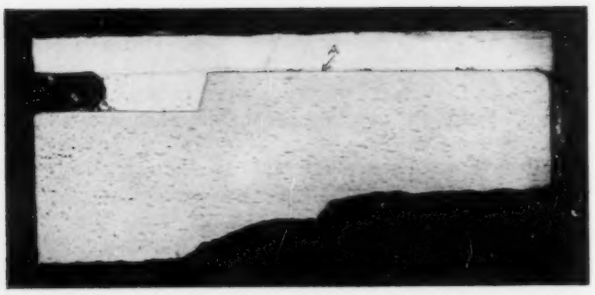


Fig. 9—Low-Power Photomicrograph Showing Cross Section of a Joint Brazed in a 4-Tube Bundle Along with the Large Bundle. Note How the Silver-Brazing Alloy Has Filled the Reservoir and Flowed Throughout the Joint. 4X

2. Fluxing. Brush the tube ends and the bored openings with a thick solution of flux and water.

3. Brazing Metal. Use bands of silver brazing alloy 0.050 inch thick by $1/4$ inch wide, the inside top diameter being from size to size to about 0.003 inch larger than the outside diameter of the tube to provide for easy assembling.

4. Assembling. Insert alloy rings in the counterbored recesses in the tube sheets and coat them with flux. Then insert the tubes.

The seven tube bundle, after being prepared according to this procedure had two steel rods welded to the sides of its tube sheets in order to hold the latter apart the proper distance. Then the assembly was set up in the bell-type furnace and brazed, using gas No. 2, and with thermocouples on the top and bottom tube sheets to provide a check on the temperature uniformity. This was found to be equal to expectations and examination of the brazed assembly showed that the silver brazing alloy had flowed throughout all joints. A steel jacket was then put around this small tube bundle and the assembly was given a hydrostatic test at 3000 pounds per square inch pressure. The tubes collapsed at 1000 pounds but all joints were found strong and tight at 3000 pounds pressure.

It was then concluded that sufficient preliminary tests had been made to warrant going ahead with the large tube bundle. Accordingly, a large bundle was designed and constructed on the accepted lines of design as recommended and approved by the A. S. M. E., but the tubes instead of being expanded and ferruled as in the conventional design, were fitted into the heads as shown in Fig. 7, and the foregoing procedure for preparing and assembling the parts was followed. Special attention was given to the manner of supporting the large assembly, particularly with respect to preventing the tubes from sliding through the bottom tube sheet and supporting the top tube sheet. A steel screen was fastened in place at the bottom to hold the tubes in place, and supports around the side as shown in Fig. 6 held up the top tube sheet. These supports were designed so that the upper tube sheet could be lifted from them by the copper tubes if the expansion of the tubes should cause this effect during heating. The supports also were tied to a lifting lug above the assembly.

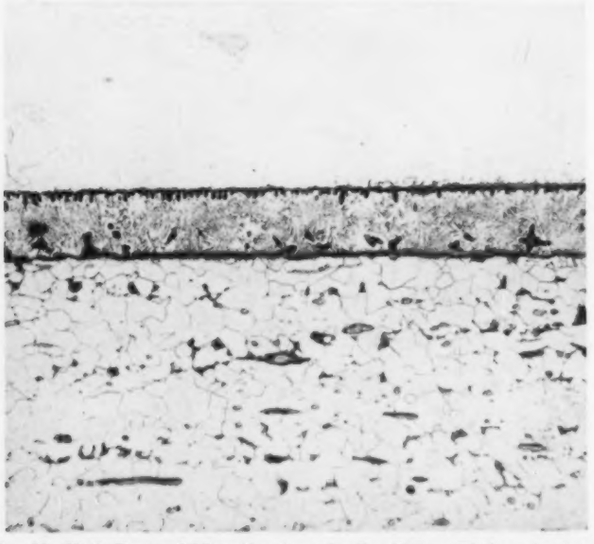


Fig. 10—High-Powered Magnification of a Small Area Within the Joint Shown at *A* in Fig. 9 175X

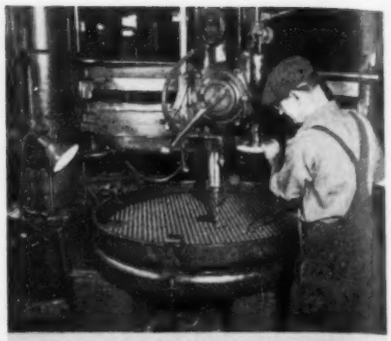


Fig. 11—Drilling Both Headers and Dry Plate in One Operation

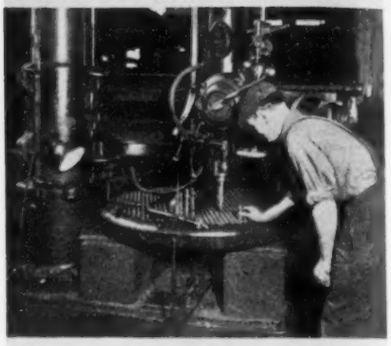


Fig. 12—Headers Are Reamed to Give the Proper Tolerance. Brazing Alloy Reservoir Is Bored at the Same Time

Fig. 13 — Removing Sharp Edges from Tube Holes

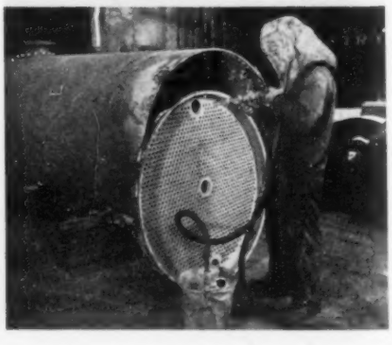
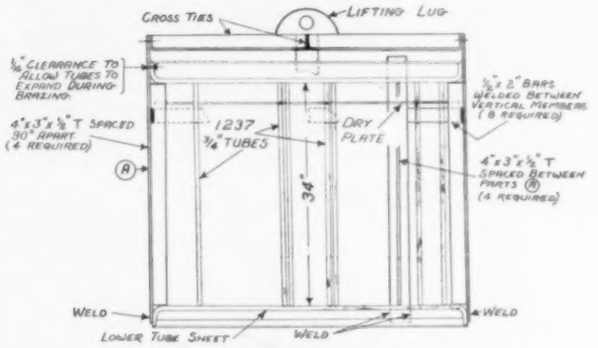


Fig. 14—Sand - Blasting Headers to Remove All Grease, Dirt and Oxide

Fig. 15—Pickling Copper Tubes in Acid Bath to Remove All Dirt, Oil and Oxides

Fig. 16—Fluxing Each Tube Hole and Inserting Silver Brazing Alloy Rings

Fig. 17—Inserting Tubes in Tube Sheets and Fluxing Tube Ends




CRADLE FOR SUPPORTING TUBE BUNDLE DURING HANDLING & HEATING OPERATION

Fig. 18

Six thermocouples were placed in the charge, some of which are evident in Fig. 6. Three of these thermocouples were placed in contact with the copper tubes so as to represent the temperature of the metal and three of them were placed within the tubes to indicate the temperature of the gas circulating through the tubes. The relative locations of the thermocouples are indicated and explained in the sketch and caption of Fig. 8.

A small 4-tube bundle with members having the same section as those in the large bundle was placed in a recess in the periphery of the tubes and supported on the bottom tube sheet. This assembly was prepared in the identical manner as the large one so that after brazing it could be cut up and examined under the microscope to give an indication of the results obtained in the large assembly. The pedestal on which the tube bundle rested as shown in Fig. 6, encloses a fan which is driven by a motor mounted beneath the supporting base. This fan circulates the gas atmosphere throughout the entire heating and cooling cycles. Gas was supplied by an inlet coming up through the base. To the right of the tube bundle in Fig. 6 is shown a sheet alloy retort which was placed over the charge and rested on the base, with a lip on its flange resting in a liquid seal. The protective atmosphere was maintained within this retort. The installation shown includes four bases and four retorts so that several charges can be cooled while one is being heated. At the left in Fig. 6 is the bell-type furnace shown resting on the floor, which was placed over the retort during the heating cycle but taken off and put back on the floor during the cooling cycle.

Figure 8 shows a record of the temperatures throughout the charge during the entire heating and cooling period. The solid lines show the temperature of the metal at the top outside, top center and bottom outside. The three thermocouples indicating the temperature of the gas circulating throughout the charge gave almost identical readings and these readings are indicated by the curves 4-5-6. It will be observed that when the gas temperature reached 1160° F. which is just beneath the melting point of the silver brazing alloy at 1175° F. power was turned off the furnace for fifteen minutes in order to assist the lagging portions of the charge to catch up with the hottest portions. Then the bottom heat was turned on but the top heat was not. This further assisted equalization of temperature. Finally when the maximum temperature differential was only plus or minus 9° F. with a peak temperature of 1238° F. the power was turned off and the furnace was removed. Then a circular pipe was put over the top of the retort and water was sprayed on the retort wall to accelerate the cooling.

Upon completion of the cooling cycle, the retort was removed and the brazed charge was given a visual examination. It was found that the copper tubes had re-

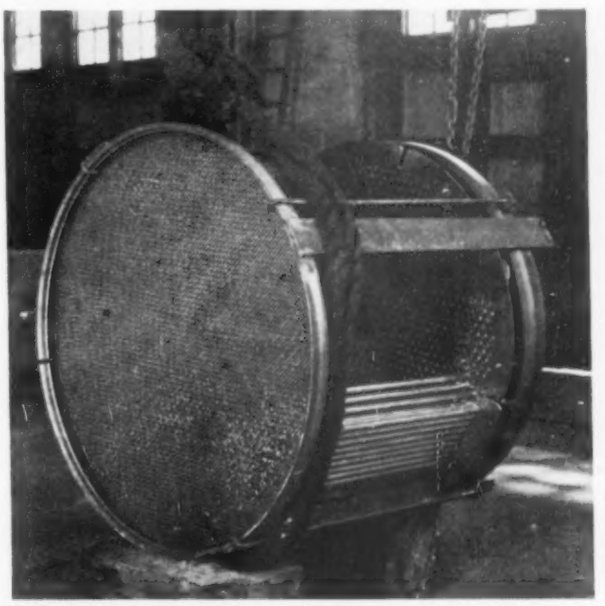


Fig. 19—A Temporary Retaining Screen Fastened to the Bottom Header Prevents Tubes from Moving During Heating

tained most of their brightness, but the steel tube sheets were slightly oxidized. The silver brazing alloy had apparently penetrated through all joints leaving fillets at the under side. The small sample had a similar appearance and it was taken to the laboratory for microscopic examination. A study of the samples indicated that there had been no ill effects whatever from the atmosphere or from the time temperature cycle employed, and on the contrary, the results were considered to be excellent in all respects. The silver brazing alloy was found to have penetrated throughout all joints indicating strong, tight bonds. Figures 9 and 10 show typical cross sections taken through the joint. Figure 9 is a low power magnification of the complete cross section showing the silver brazing alloy cast into the counterbored reservoir and also the alloy throughout the bond between the copper and the steel. Figure 10, a high power photo-micrograph, was taken at the point marked *A* on Fig. 9.

## TESTS ON TUBE BUNDLE

The large tube bundle, after furnace brazing, was subjected to a series of rigid tests to determine the tightness and strength of the joints. It should be noted that the ends of the tubes of this bundle were not beaded. Accordingly, the strength of the joints was solely that imparted by the silver brazing alloy. The assembly was first tested hydrostatically at 330 pounds pressure, during which procedure no leaks could be found in the joints. Then it was given a series of 45 severe steaming cycles in the boiler, each cycle consisting of raising the pressure from zero to 225 pounds, then shutting off the burner and blowing the boiler back down to zero pressure. Each cycle was completed as quickly as possible in order to develop maximum strains in the tube bundle. Following the twenty-fifth cycle, it was decided to go to extremes with the tests in order to eliminate any shadow of doubt regarding the strength of the assembly. Therefore, the pressure was not only raised from zero to 225 pounds, the burner cut off, and steam blown to the atmosphere as usual, but while this was occurring the blow down valve in the water leg was opened, emptying the boiler of all water and steam. Into this hot dry boiler was pumped cold feed water up to the normal water line. After successive firings all furnace brazed joints were still found to be perfectly tight. Such severe service would never be encountered in actual practice and mechanical joints could never withstand such treatment, but the knowledge that the furnace brazed tube bundle could "take it" was desirable information.

Following these steaming tests, which were made in the shop, the boiler was installed in an electric locomotive and put in actual service. On September 1, 1938 it had been in service about three months and indications were that it was still in the same condition as when installed on the locomotive.

## COST SAVINGS

The main objective in developing the furnace-brazed tube bundle was to eliminate the high maintenance expense on the present boilers. Unfortunately no actual figures on maintenance are available. However, it is practically a foregone conclusion that the furnace-brazed tube bundles will justify themselves by the reduction of maintenance costs.

It is also hoped that by this construction the complete retubing of the boiler every four years can be eliminated. The construction is such that the complete tube bundle with heads attached can be readily removed without disturbing the tubes in the heads, to permit inspection of the inside of the boiler. If the same tube bundle and heads could be rewelded in place, a saving of approximately $500 per boiler could be secured. Such a procedure would of course require approval by the I.C.C.

## CONCLUSION

Based on the success of the first furnace-brazed tube bundle, the manufacture of additional units has been started. It is apparent that this new method offers important advantages over the former methods and in the light of successful furnace brazing of other types of assemblies using silver-brazing alloys, it is likely that this method will find general usage in the manufacture of tube bundles for vertical fire tube boilers.

The authors gratefully acknowledge the assistance of Leo Edelson, Handy & Harman, New York, N. Y., and L. L. Wyman and O. S. Haskell, General Electric Co. Schenectady, N. Y.

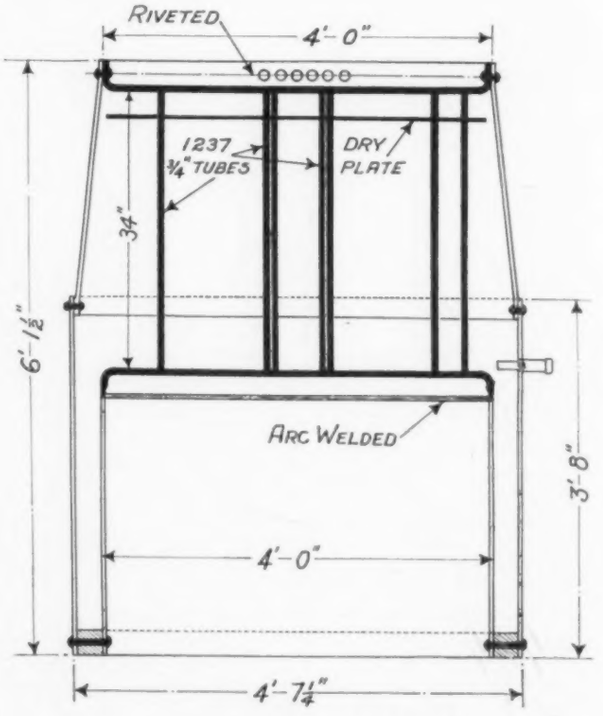



Fig. 20—Dimensions of Boiler Shell

Fig. 1—General View of a Miscellaneous Group of Small Parts Including Full Wire Group

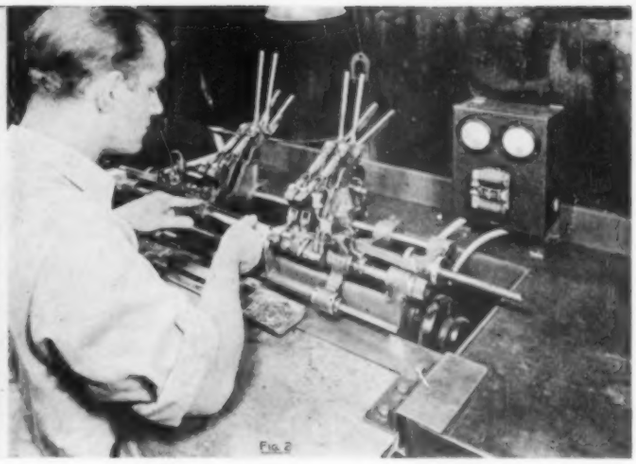


Fig. 2—Wire Welder in Operation

# METHODS for the MANUFACTURE of Precision Assemblies by Resistance Welding*

By F. D. ROGERS†

AT THE outset, it would probably not be out of order to say that each one of us here at this and other sessions during the week have, in one way or another, a more than ordinary interest in welding. If this were not so, it is likely that there would be no convention. Perhaps the attraction lies largely in the great number of different applications to which welding has been and will further be put. Some of these uses seem to be so far apart that the relationship of one to the other is hard to define. Many are as spectacular as they are massive and are, as a result, in the public eye a great deal. These are truly monuments to welding which reach into tons of materials and many thousands of pounds stresses.

Contrast with this thought, if you will please, the comparatively minute size and great variety of parts to which resistance welding is daily applied in the main plant of the International Business Machines Corporation in Endicott, New York. A few of these are displayed here (Fig. 1) and several will be described as we go on. Where others deal with tons, we are concerned with ounces or fractions of an ounce, and instead of feet or inches, we must think continually in terms of thousandths of an inch. In addition to this minute size and close tolerance, and because of the nature of our manufacturing set-up as a whole, we must be prepared to produce all the way from ten or fifteen assemblies, to ten or fifteen thousand assemblies at any time. Perhaps with the small job, we may have no more than a "nodding acquaintance" since it may have been three or perhaps six months since that particular job previously passed through the welding room. The above is somewhat explainable in that during the past year, we had in active production over forty different classes of business machines, with approximately 600 models, involving the handling of some 50,000 different parts and assemblies, ranging in size from those as large as a pin head to those weighing upward of 350 pounds. One model alone, the Alphabetic Tabulator, is made up of 2700 different items, with nearly 55,000 separate parts. Years of experience in such a tremendously involved program has indicated the desirability of providing for such parts and assemblies usually in quantities suitable for three months' production; or in other words, each one, on the average of the 50,000 different items mentioned, is put through our manufacturing set-up four times each year.

The line of business machines into which these many parts are assembled serve a wide variety of recording and accounting purposes.

Now, what does this mean when associated with any one of many different processes or methods required in producing them? It means that *that* particular process must be none the less accurate and dependable than the machine it helps to fashion.

Four years ago, our company, in line with its ever-progressive policies, began a definite program of advance in the application of welding to the manufacture of our products. The possibilities of resistance welding for small assemblies was at once apparent and it is around this group that our comments are made.

In point of comparative figures, only a very small portion of the vast number of parts and assemblies previously referred to reaches the welding room in their path to completion. Perhaps this is very fortunate for us who have to contend with the headaches which go with some of them. However, by building upon a sound foundation, we have enjoyed a steady growth in this

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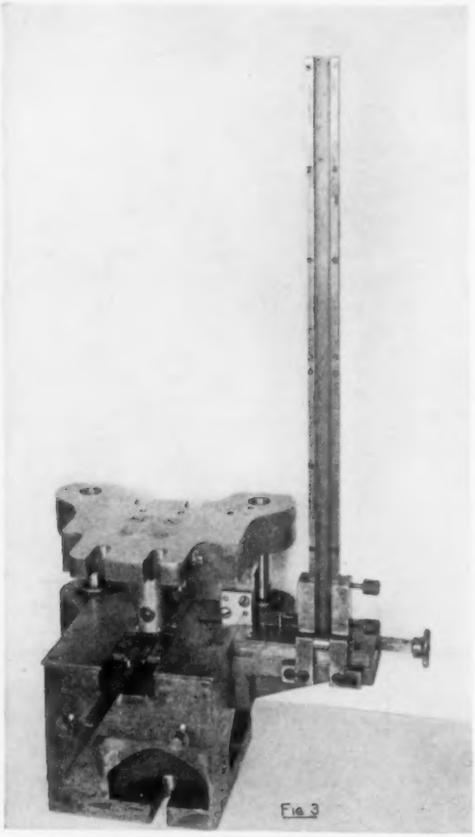



Fig. 3—Automatic Fixture for Filler Block in Type Bar

field from a very humble beginning, to a point where we now have between 200 and 300 different items of precision resistance welded assemblies being regularly handled in active production, in addition to the various other welding and brazing applications.

Illustrative of the group of those items of considerable quantity which are in continuous production, is the pull-wire group (Figs. 1 and 7). This little unit may be likened to a "sinew" in electric accounting machinery by which the "nerve" impulse through the magnet is transferred into mechanical movement. It consists of three separate parts—two terminals and a wire, butt welded into a unit. Because these units must perform millions of operations without appreciable wear, high-carbon steel is used for the terminals and suitably heat treated after assembly. The wires themselves are also high-carbon music wire, mainly for stiffness, since somewhat of a "push" is transmitted under certain conditions of operation. Because of the accuracy maintained throughout these "magnet units" of which these wire assemblies are a part, it is necessary to hold the over-all length from center to center of holes to plus or minus 0.003 inch. These parts are welded in a specially developed dual welder which completes a wire assembly for each machine cycle. The machine (Fig. 2) is hand operated up to the present time, though it is planned in such a way that automatic operation—with exception of set-up and removal of parts—may be added if and when desirable. Slide drives are somewhat unusual, being in the form of spring energized hydraulic cartridges which are compressed in the opening operation in the cycle. Upon release, the designed escapement of fluid allows movement of slide which is *exactly* proportionate with the softening of the wire end. At nearly the full extension limit of the cartridge, escapement is inceeased so that, in effect, a small upsetting surge takes place simultaneously with the breaking of welding circuit, with the full extension of cartridge restricted to an exact linear dimension. The advantage of this arrangement will be seen when these three factors are considered: first, the exactness of over-all length required; second, the unusually small section area of the weld; and third, the brittleness of the structure as welded.

These factors do not permit the maintaining push-up pressure on the welded joint during cooling, nor pushing up to a mechanical stop in the slide, without considerable breakage. All three conditions are satisfied, however, by pushing up as described to a positive position and, at this point, *removing all mechanical energy* from the system.

It may be of interest to add that over a production of approximately half a million parts, the total rejection traceable to faulty welding, either structural or dimensional has been less than 0.4 per cent without a single report of a failure in service.

Referring to a second group on which production is of an intermittent nature, and by far the greatest in point of number of different items, we should add here that all

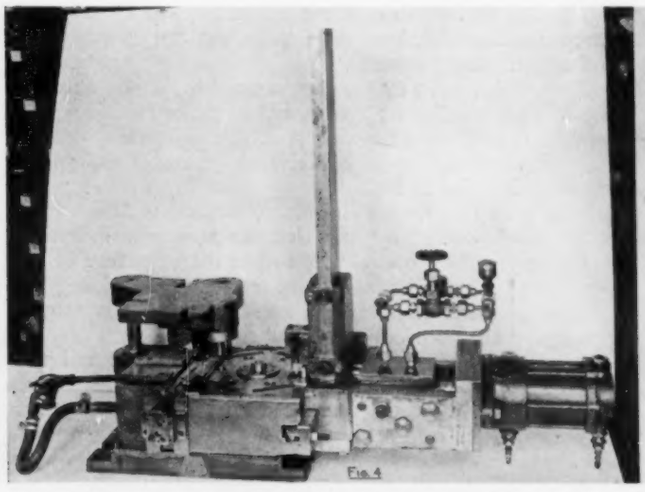



Fig. 4—Automatic Fixture for Rack on Type Bar

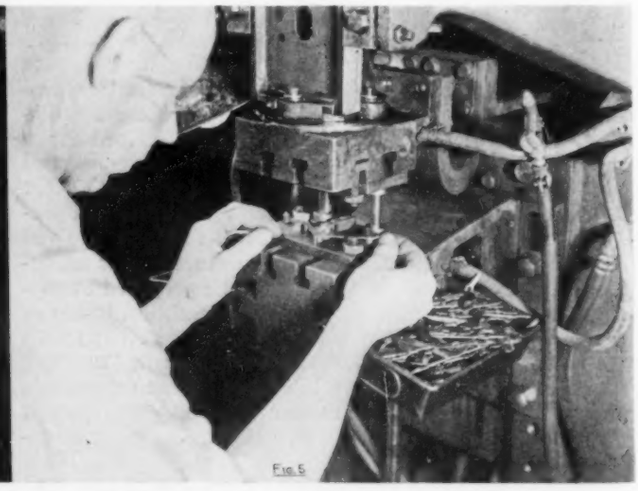



Fig. 5—Operator at Press Welder During Production

of our spot and projection welded production falls into this category. Only a few of these have been selected for discussion where conditions are illustrative of the main point at hand, namely, accuracy. The type bar assembly herewith is a good example of a relatively higher quantity production item (Figs. 1 and 8). This part under normal manufacturing conditions will appear in lots of 10,000 pieces on an average of once a month. Good operating conditions will pass such a quantity through the two operations in a relatively short time so it must be tooled in such a way that it can be set-up on a general utility machine without appreciable delay of the latter. This, in itself, would not present such a problem if it were not for the dimensional accuracy required in the unit. The small filler block in the large end must bear a relation to the upper type slot of minus zero to plus 0.003 inch from mean dimension and the two must be parallel. The rack below must be positioned to plus or minus 0.002 inch from the mean dimension between middle tooth and middle type slot. The width of rack and bar from face of teeth to back of bar must hold to within plus 0.001 inch minus 0.002 inch from the mean dimension.

To accommodate both production and accuracy conditions, rather elaborate, self-contained fixtures of the magazine feed variety are provided, as may be seen pictured on display panel (Figs. 3 and 4). Both of these provide for the manual handling of bar component only, which is nested loosely in the fixture in its open position. Block or rack as the case may be is fed automatically to position and the whole unit automatically clamped up preceding the welding impulse, after which the assembly is withdrawn manually from the apparatus. Filler block is attached with two projections and rack with three, in each case welded simultaneously in parallel.

A further form of projection welding that we call "ring" welding, and which we know has considerable promise, is now being used to quite some extent. The samples of another variety of printing unit are illustrative of this method (Figs. 1 and 9). This particular "family" consists of five related parts all using the same hub or bushing and one part which has a flat member

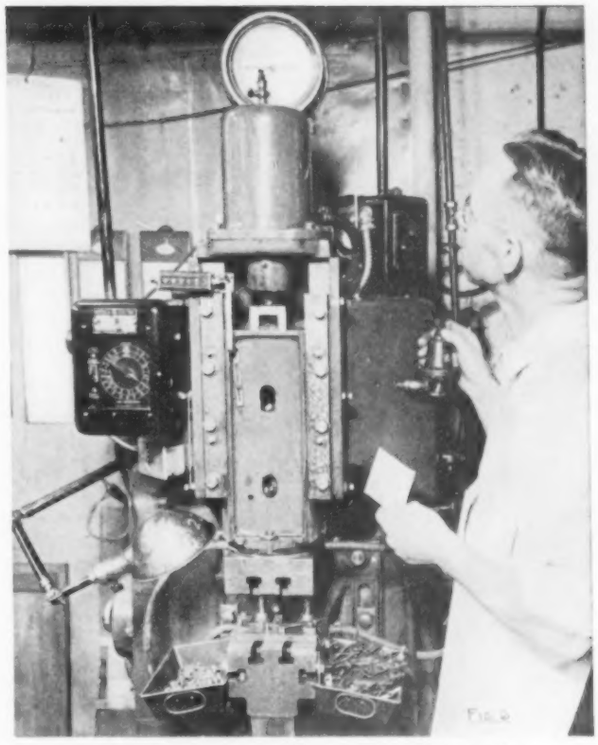
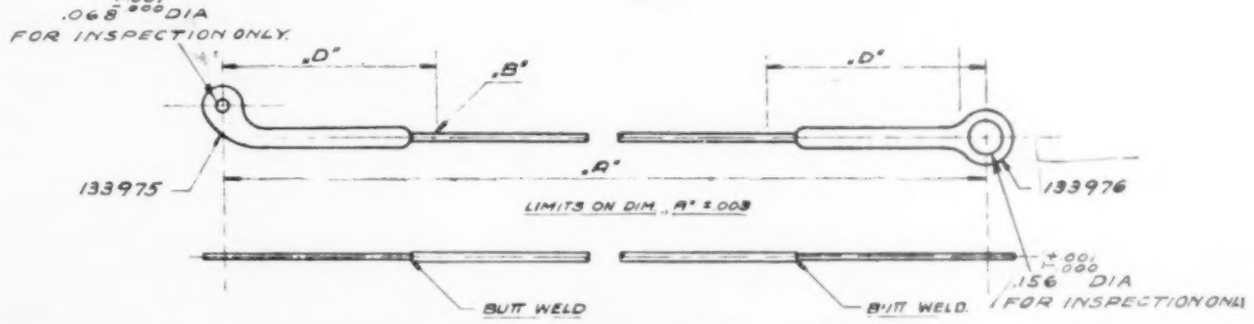


Fig. 6—Setting Up Press Welder from Card Information

FIG. 7




| PART NO | MATERIAL |
|---|---|
| 133975 | ANNEALED SPR. STL. |
| 133976 | " " " |
| B | MUSIC WIRE |

| PART NO | DIM. "A" | REQ'D | MAGNET SECTION | POSITION | PART NO OF "B" | REQ'D | MAGNET SECTION |
|---|---|---|---|---|---|---|---|
| 134481 | 3.844 | 8 | 80 COIL | 1ST | 133977 | — | 45 Coil |
| 134482 | 5.031 | " | " | 2ND | 133978 | 8 | " |
| 134483 | 6.219 | " | " | 3RD | 133979 | 8 | " |
| 134484 | 7.406 | " | " | 4TH | 133980 | 8 | " |
| 134485 | 8.594 | " | " | 5TH | 133981 | 7 | " |
| 134486 | 9.781 | " | " | 6TH | 133982 | 7 | " |
| 134487 | 10.969 | " | " | 7TH | 133983 | 7 | " |
| 134488 | 12.156 | " | " | 8TH | 133984 | — | " |
| 134489 | 13.344 | " | " | 9TH | 133985 | — | " |
| 134490 | 14.531 | " | " | 10TH | 133986 | — | " |

NOTE: BUTT WELD, HEAT ENDS IN LAVITE AS SHOWN BY DIM. "D" TO APPROX. 1450° F. & QUENCH EYES ONLY, IN OIL. TEMPER ENTIRE ASSEM. AT APPROX. 325° TO 375° F CADMIUM PLATE .0002" - OVEN DRAW APPROX. 1 HR. AT 250° TO 300° F. - REMOVE PLATING FROM HOLES.

Fig. 7—Detail of One Item of Pull Wire Group

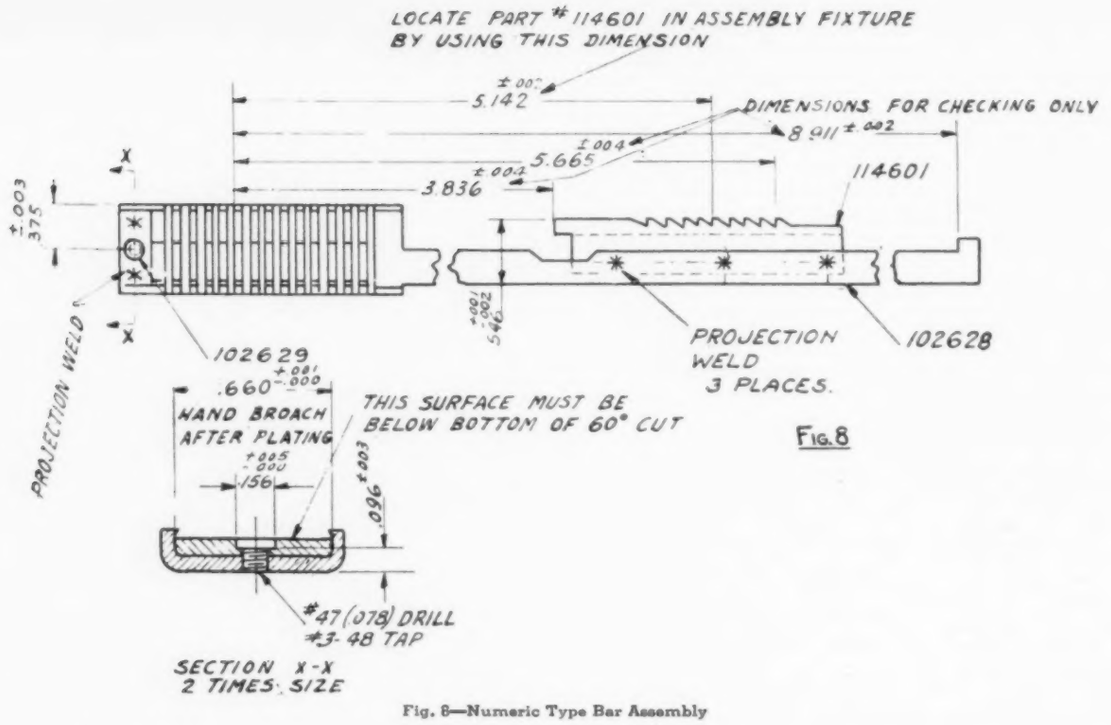



FIG. 8

Fig. 8—Numeric Type Bar Assembly

attached to either end of a double tenoned bushing. In this method, the screw machined bushing is provided with a suitable bevel at the root of the tenon and it is this material which is used to provide the weld attachment. In this group, the principal tolerance conditions are: first, over-all thickness of assembly to be held to plus zero, minus 0.0005 inch from mean dimension; second, an over-all hole diameter variation of not over 0.0005 inch is allowed; and third, the positioning of bushing center with respect to rack teeth must be such as to permit free operation of latter with mating part but without noticeable backlash. Bushings are completely finished as such and attached to flat parts in a manner to meet the above conditions. The result is a welded assembly having "no visible means of support." That is to say, a soundly welded attachment capable of transmitting all the torsion required of it and to spare, but completely enclosed within the finished part, yet meeting the accuracy conditions described.

Since the different members of this family run into considerably lesser quantities than the earlier example given, the fixture group is hand fed. A single guide pin type of holder is used for all with an individual subfixture interchangeable with it to suit the holding requirements of the several parts.

The small disk and bracket assembly illustrated (Figs. 1 and 10) is one of the sizable group of low production items but still one in which accuracy is a factor in the proper functioning of the miniature overdrive clutch of which it is a part. This unit is subjected to relatively high intermittent loading and yet must pick up precisely at the proper time. It is, therefore, necessary that the five plunger brackets be very closely related to each other and to the indexing holes in the plate. The fixture for this item is a small, turn-around, hand-operated device with an anvil for holding one bracket at a time which is loaded in the open position of a hand-operated upper member hinged to the base. The plate, once loaded, is turned around to successive positions for five machine trips per assembly, welding 2 small projections at each trip.

So much for a brief touching upon specific cases. It is in providing for this constantly changing condition of parts and quantities without sacrificing in uniformity and dependability from piece to piece and from lot to lot that the real problem lies. We hardly need stress the fact that all elements must be thoroughly planned and competently carried out Any general method of inspection of such joints is hardly to be considered as a precaution against failure, hence the fact that the responsibility for the process lies almost wholly within the process itself. This means, first of all, that the welding equipment must be of a most dependable and versatile nature. Our newest machine is a precision press welder equipped with air-cushioned, power-driven head, and electronic power control. It is provided with forty stages of heat in practically straight line increments of increase throughout its range, with all operating controls at the finger tips (Figs. 5 and 6).

Schedules of proper pressure in pounds on the ram and approximate current dwell in cycles are provided at the machine for the operator's general guidance in setting up new jobs. These schedules are standardized for the variety of jobs to be expected, such as, for example, the size and number of projections, number of spots, etc. With these factors established and parts design properly carried out, it is necessary only to build up the welding heat until a sound joint results. Once established, this setting is recorded on an operation card as will be noted in photograph illustrating this method (Fig. 6). . There are three marked advantages in this general procedure for our purpose, namely: first, less loss both of time and set-up pieces in casting about for proper settings on a new part since generally only the heat variable is to be found. Very often a close enough similarity between the job at hand and some earlier job already recorded permits the full selection of machine setting without trial. Second, a job once set up and all factors remaining constant, we need not be too concerned if the same item is not run again until some indefinite future time for all necessary information is at hand when it appears. Third, for manufacturing flexibility, the same job may

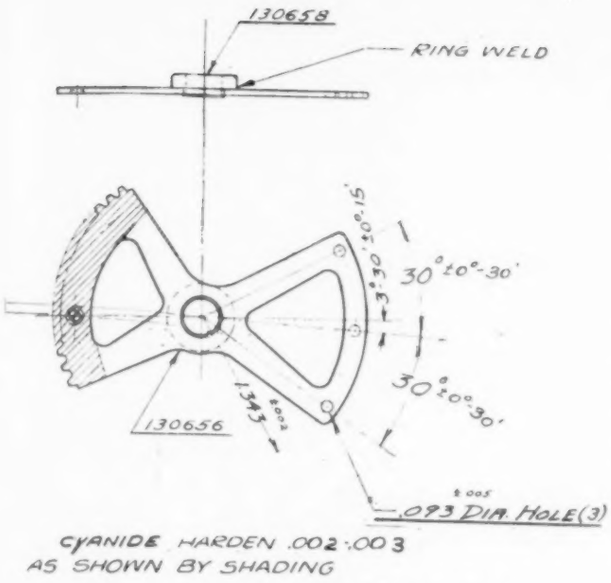



Fig. 9—Detail of One Item of Type Sector Group

be switched from one machine to another when operating conditions require, and uniformity maintained in the move, since the principal variable will be the different heat setting due to individual circuit characteristics of the particular machine. In many cases this latter may be interpolated from the setting already established and, once found, is itself added to previous information.

The design of tools used must be carefully thought out to the best interests of the particular job at hand, followed by accurate building and careful maintenance. Generally, the nature of our precision work dictates jump-weld fixtures in which the parts are welded through the fixture itself, the latter being either clamped down to flat faced knee or moved at will on a similar flat surface as the case may require.

Fixtures are built on nonferrous bases, usually copper bus bar or copper alloy and care is exercised to insure complete insulation. With these fixtures kept clean and in good condition at all times, this plan promotes uniformity of work since fixture-effect variables are reduced to a practicable minimum. In some cases where it has been found difficult to maintain gage pins when insulated to avoid shunting, we resort to the use of ground pins of annealed glass to provide for accurate location of parts over a long period of time.

A few words about our standard of projections may perhaps not be amiss. From the outset of our projection welding efforts, a set of conditions stood out which influenced a choice in this respect, which at first glance, may appear to be not the best. First is the necessity for control of distortion in the parts to be embossed. We believe—and our results over many thousands of pieces welded prove our belief—that for the nature of our work, a simple embossing such as is obtained with a flat end, round punch is the best. The diameter of punch and hole in the die side correspond and the edges of both are slightly dulled—not much, just a trifle. By a standard of diameter and height of embossing which is related to thickness of flat, we obtain a suitable attachment with a minimum of parts distortion. Secondly, distortion at assembly must be avoided. This requires the smallest attachments practicable in keeping with the use to which the part is to be put, and the shortest welding dwell compatible with accuracy. Obviously, then, these attachments do not represent fullest shear strength obtainable in keeping with the material and thickness. When tested, these welds seldom pull a slug out of the sheet excepting where an attachment happens to be made to a very thin piece. The failure is usually a shear through the attachment. We would not recommend the general adoption of such practice except where circumstances absolutely warrant, but where they do, our results demonstrate its practicability.

We have one rather pleasing general condition in connection with material which all of you will appreciate at once. That is to say, most of our production resistance welding is done with plain low-carbon steels of excellent surface condition. This in itself, goes a long way in the removal of difficulties. However, along with this comes the exceedingly bitter pill that in a large number of cases, assemblies are locally case hardened at points. This would be all very well if it were always possible to do this after the welding. However, this is not the case and consequently a very careful routine must be followed in order to avoid severe welding embrittlement, since the carbon content at the surface is then of the order of 1%. A schedule has accordingly been devised for the guidance of engineering and routing sections, describing an *even dozen* different combinations of carburizing, cyanide or aero case hardening either locally or completely and their relations to welding.

The two production cases described earlier, though they were not selected for the purpose, represent two of these methods of obtaining local case hardening. The rack on the type bar is aerocased on the tooth surfaces only. In this case the rack blank is copper plated before broaching of teeth, after which it is aerocased and copper removed. This provides for a local hardened assembly, with hardening already accomplished on a component part when it is obvious, from the previous description of job tolerances, that any form of heat treating after assembly would be impracticable. On the other hand, the sector and hub assembly is done with parts in their natural state, after which that portion of the lever embraced by rack teeth is local case hardened.

There is still one important factor contributing to the successful carrying on of its class of work under the conditions described, which has not been touched on up to this point, not because it is by any means a minor one but rather, to impress it upon you in concluding. This is the factor of human element. By this I do not mean wholly as it is evidenced in the operation at the machine from piece to piece although this too requires good judgement, care and watchfulness on the part of the personnel.

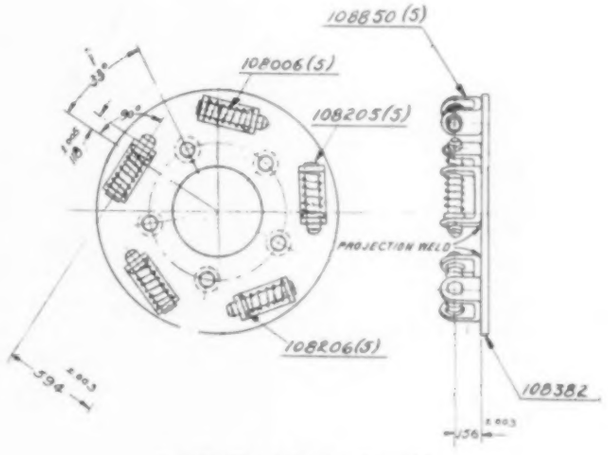



Fig. 10—Clutch Washer Assembly

What I refer to mainly in this respect is the fact that a typical part or assembly, in its growth from the engineer's idea to a functioning part in a machine, passes through a great many hands. When such a part is to be a welded assembly, we can hardly expect that all of these moves will be looked at from the welding standpoint alone. Therefore, if we are to expect it to become a satisfactory welded assembly, it must be carefully guided throughout its moves through drafting room, planning, tool design and manufacture, and finally through the set-up stage at the welding machine. It may THEN be left in competent, watchful hands, with frequent observation by those responsible for the well-being of the process generally.

After several years' experience, we are pretty firmly convinced that painstaking care all along the line, together with the best of equipment, must be provided in producing this class of small precision welded parts with a degree of regularity which will place the dependability of the process beyond shadow of doubt, for if it is to have general acceptance at all, this can *only* come about through absolute dependability. It is not in any sense a spectacular application of modern welding, but, to those who are directly interested in its growth, it is an exceedingly interesting one.

In comparison with mechanical fastening methods which are usually necessary where some form of welding or brazing is not used, the economy of the resistance weld attachment may be taken for granted. But this economy will not answer for large rejection for either dimension or weld failure, and especially so in the case of the class of product which it is the privilege of the International Business Machines Corporation to supply to the world at large.

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Fig. 1—Contractor's Welding Truck Equipped with 300 Ampere Welding Machines Used in Oil-Well Casing Welding

Fig. 2—Preparing the Bottom Joint by Welding a Float Collar in the Middle and a Guide Shoe Near the Spigot End

Fig. 3—Oil Well in Hastings Field, Texas Gulf Coast Area Where 9 5/8-Inch Casing Was Welded

# OIL-WELL CASING WELDING*

## An Opportunity for the Welding Industry

By W. MIKE MURPHY†

THE welding industry is a service industry obtaining its income from all of the other great industries where metals are joined. We maintain as a fundamental principle that where steel parts are to be joined to form a permanent unit, the job can be done better with welding. A real opportunity is offered for service to the oil and gas industry where more than a million tons of steel pipe is being joined each year into casing strings.

We are interested in expansion of the market for welding services. The production division of the oil and gas business offers an addition of at least six million dollars per year to the income of the welding industry through casing and is, itself, accepting responsibility for leadership in its development. If all of the casing run in oil and gas wells in the United States were welded, it would provide continuous employment for a thousand skilled welders and an equal number of auxiliary employees.

Casing was one of Colonel Drake's greatest problems in drilling the first oil well in 1859. Since that time, nine hundred and forty thousand oil and gas wells have been completed in the United States. During 1937, twenty nine thousand wells were drilled in this country at a total cost of more than six hundred and eighty million dollars. The oil and gas industry has grown to be one of the major producers of wealth in this country. Casing is still an important problem of the industry.

The first oil well was completed at a depth of sixty-nine feet. The average depth per well completed in 1937 was thirty-two hundred and thirty feet. One-fourth of United States oil production is from depths below five thousand feet. It is generally believed that the greater part of shallow oil sources have been discovered and that future discoveries will be made at increasing depths. The world's deepest well has been drilled below fifteen thousand feet. As a part of the casing problem, the importance of the casing joint increases with greater drilling depths.

The casing problem, as a whole, belongs to the oil and gas industry. The design of suitable casing is the responsibility of pipe manufacturers in cooperation with oil and gas producers. It would be impossible for the welding industry to assume leadership in study of this

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† Air Reduction Sales Company, Dallas, Texas.

problem. The joint problem is ours in cooperation with the oil and gas producer and the casing manufacturer. It is our job as welding operators, engineers, contractors, and manufacturers to develop welding methods, tools, and materials for casing welding, to assist casing manufacturers in the design of proper joints for welding, and to provide convenient and dependable welding service to drilling operations of the oil and gas industry.

The purposes of casing are to protect drilling operations from caving hole and intrusion of water and gas from intermediate sands and to provide a permanent opening from the producing zone to the surface. External pressures on casing and bottom hole pressures in wells increase in almost direct ratio with depth and can be estimated at a half pound per square inch of surface per foot of depth. Depths are being reached in drilling that require casing of special high yield point steel to resist collapsing pressures. The load on casing joints increases in direct ratio with the length of casing strings. To provide ample safety factor in the joint with steels of higher yield point, the strength of the joint must approach more closely the strength of the pipe. Welding, alone, offers this quality in a pipe joint.

The use of welding in the oil and gas industry originated with refining operations. When welding was introduced on construction and operation of pipe lines, the pipe lines depended on their associated refineries for information on welding methods and for assistance in supervision. In less than twenty years, the welding of pipe has been advanced to a high degree of perfection on pipe line construction. The source of information on pipe welding has been reversed. It is quite common for refineries to call upon their associated pipe lines for assistance in design and supervision of pipe welding.

Casing welding enters a field of more importance to the oil and gas industry. Starting with an adequate supply of qualified welders, oil and gas producers will rely on the experience of their associated pipe line companies for information on pipe welding, but it can be expected that production operations will take the leadership in advancement of pipe welding, and within a few years will be the source of information on this subject for the other branches of their industry.

In the development of casing welding, as in the progress of improvement of pipe line welding, criticism can be expected, and will serve a useful purpose in directing engineering effort and practical thought to the correction of faults. Discouraging failures will be the source of information for the adoption of suitable operations and establishing fundamental principles of joint design.

The oil producing companies will profit most from the welding of casing. The price of casing with ends prepared for welding is quoted at fifteen per cent less per ton at the mill than for similar threaded-and-coupled casing. Including the cost of welding and additional rig time in the comparative additional cost of running welded casing with present methods and subtracting this from the saving in cost of pipe alone, there will be left a net average saving of approximately a cent per diameter inch per foot. Improvements in rig tools and methods of handling pipe in running welded casing can be expected to produce an increased comparative saving. If all of the casing being run in oil and gas wells were welded it would produce a saving of something more than five million dollars per year to the oil and gas industry. One large producing company alone, now taking active part in the development of casing welding, could expect a saving of more than a quarter million dollars per year if all of its casing were welded.

Of primary importance to the development of casing welding, but to whom there is the least evidence of immediate gain, is the pipe manufacturer. Active, sincere cooperation is being furnished by the leaders following the principle that it is the obligation of a manufacturer to furnish materials suited to the advancing needs of the industries served. Less farsighted manufacturers will be forced by competition to take part.

The hope of reward is from an increased and continuous demand which may result from the specific advantages of welded joints. The introduction of welding in pipe line construction made the building of gasoline lines practical, increased the construction of oil lines by reducing the required pipe weights, and made the construction of long large diameter gas lines an economic possibility by reduction of operating hazards. Welding of casing may encourage deeper drilling with an increase in the average length of casing strings. There is evidence that, conservatively operated, a greater number of wells will increase the ultimate recovery of oil from any producing area, the limiting influence being the compari-

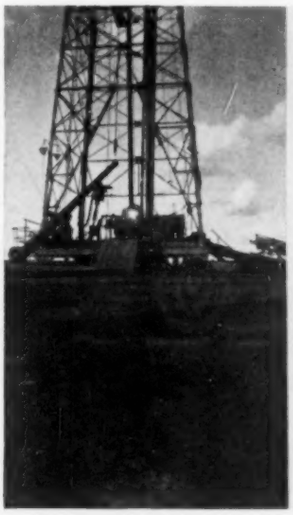

Fig. 4—Welding 9 5/8-Inch Casing String in Hastings Field, Texas Gulf Coast Area

Fig. 5—Welding Operators Standing on Rotary Table While Welding 9 5/8-Inch Casing in Hastings Field

Fig. 6—Same as Fig. 5. Note Straightledge Leaning Against Drill Pipe for Alignment of Joints

son of expected additional yield with increased investment. Drilling economies will increase the number of wells which may be profitably drilled.

To drilling contractors and to more than sixty thousand members of crews on the four thousand drilling rigs, casing welding offers an improvement in the safety of operation. In running welded casing the manual operations of making the casing joints are reduced to utmost simplicity. Apart from other advantages the added safety of running welded casing is sufficient reason for the favor of drilling crews.

To petroleum engineering, including drilling and production operations the greatest advantage of welded casing is the positive gas-tight and leak-proof quality of all-welded joints. During running, the weight of the casing string may be used by working the pipe to dislodge obstructions in the hole, and if stuck the pipe may be rotated in either direction without damage or opening small leaks in the joints. The advantage of gas-tight joints in casing off intermediate gas sands is obvious and this advantage increases with deeper drilling where higher and more destructive gas pressures are met.

All of the qualities of welded casing joints are of advantage in cementing jobs. The welded joint offers less resistance to the displacement of cement from the pipe and into the annular space between the outside of the pipe and the wall of the hole. The string may be worked with safety during running of cement to assist in floating out clay and shale from around the pipe and reduction of voids in the completed cement job. Higher pressures may be used on a cement squeeze job, and for bumping cementing plugs.

The requirements of a casing joint are collapse strength equal to or greater than the pipe, sufficient tensile strength to carry the full load of the casing string with a satisfactory safety factory and finally gas and liquid tight quality. The reinforcement of welds provides a greater cross section at the welds than in the wall of the pipe thus furnishing greater resistance to collapse at and near the weld. The positive leak proof quality of welded joints is recognized by all branches of the oil and gas industry. It is the experience of pipe line companies that with qualified welders and high strength welding materials of standard manufacture now available, all but a very small part of pipe welds have greater strength than the parent metal of the pipe. Welding satisfies all of the requirements of a casing joint.

The average tensile strength of threaded and coupled joints is equal to sixty per cent of the strength of the pipe. Specially designed joints will furnish tensile strength of approximately seventy-five per cent. The weakness of all threaded and coupled joints is that changes in temperature or load on the joint will open small leaks. It is practically impossible to insure a permanent leak proof job of threaded-and-coupled joints.

At the end of 1937 there were three hundred and fifty-one thousand producing wells in this country, averaging thirty-two hundred and twenty-five feet in depth. Assuming a conservative average of four thousand feet of casing per well in the producing wells, there is now one billion four hundred million feet of casing in these wells, or more than two hundred and seventy thousand miles. During 1937 drilling of completed wells in the United States totaled ninety-four million feet. The casing run in oil and gas wells in the United States during last year was something more than one hundred million feet, or twenty thousand miles.

Drilling operations are continuous throughout the year, being little affected by seasonal changes. Approximately seventy-five wells were completed each day in 1937. Averaging four thousand feet per well over three hundred thousand feet of casing was run in wells each day of the year, or approximately sixty miles.

The oil industry can measure the certainty of its future existence by its developed reserves. At the end of 1937 the known developed reserves of the United States was equal to thirteen and one-half billion barrels, based on the 1937 production this amounts to ten and seven-tenths years supply. Annual production of crude oil in the United States is increasing at the rate of more than five per cent per year.

To maintain the known reserves in excess of ten years supply new sources must be discovered each year with potential production of greater than one hundred fifty per cent of the year's crude consumption. To maintain its relative position the oil and gas industry must drill an average of more than twenty-five thousand wells per year. It is conceded by the oil and gas industry that the greater part of the shallow producing areas have been discovered; and that new discoveries will continue to be

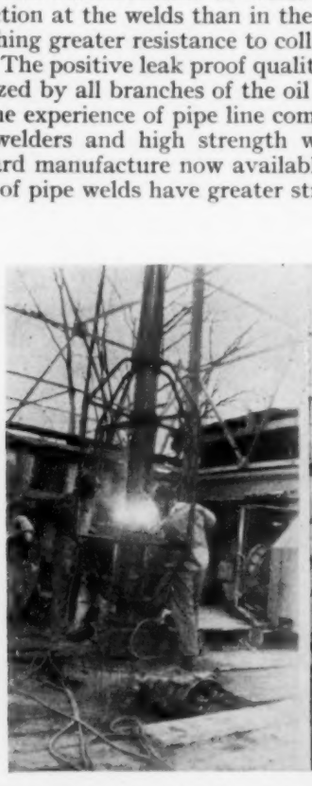

Fig. 7—Showing Casing Alignment Cage from the Latch Side. Latches of the Toggle Type

Fig. 8—Hinged Alignment Cage in Use on 9⅝-Inch Casing in Cotton Valley Field, Louisiana

Fig. 9—Welding of 9⅝-Inch Casing with Alignment Cage and Chain Bridle at Top by Which This Piece of Equipment Is Swung in the Derrick

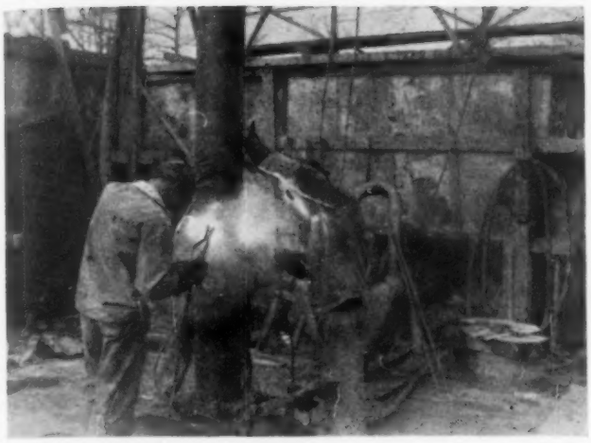

Fig. 10—Welding Operators Building Up Completed Girth Weld After Alignment Cage Has Been Removed and Weld Inspected. Alignment Cage Normally Left in Place Until Completion of Weld

made at greater depths. It is reasonable to assume that during the next ten years at least one hundred million feet of casing will be run in oil and gas wells each year.

This paper is not intended to introduce any untried methods or equipment, but to outline the field open to the development of welding in the production division of the oil and gas industry, and to report a part of what has been done. Two very excellent papers on the subject of casing welding prepared under the sponsorship of the American Petroleum Institute are recommended for reference on this subject. One written by Mr. Marvin Cook of Humble Oil & Refining Company of Houston, Texas, was read before the Division of Production of the American Petroleum Institute at its sixth mid-year meeting at Tulsa, Oklahoma on May 14, 1936. A paper prepared by Mr. L. R. Hodell, Director of Production Research of Carter Oil Company, entitled Circumferential Field Welding of Casing was read before the Eighteenth Annual Meeting, American Petroleum Institute, Chicago, Illinois, November 12, 1937. Extracts from Mr. Hodell's paper were published in the *Oil and Gas Journal* issue of November 12th and in the November issue of the *Petroleum Engineer*. The complete draft of Mr. Hodell's paper was published in four weekly installments in the *Oil Weekly* beginning with the issue of December 6th. Mr. Hodell's paper contains very valuable data collected from experience in running welded casing in wells in Oklahoma and Kansas.

Casing welding originated with the setting of welded conductor pipe. Conductor strings usually short and of large diameter, were connected with simple types of joints which could be easily displaced with satisfactory results with even a low quality of welding.

Welding of longer surface strings was not attempted until after development of improved methods of arc and oxyacetylene welding. Welding of long flow strings waited until the development of satisfactory welding practices from the successful welding of less important surface strings, and was not attempted until early in 1937. Urged by the economies of welded casing and its engineering advantages, and with a record of satisfactory welded casing jobs, the American Petroleum Institute, at its last annual meeting, gave consideration to the welding of casing for future adoption as a standard practice in the drilling of oil and gas wells.

More than two hundred strings of casing have been welded in the East Texas field using the oxyacetylene process. This method permitted the use of salvaged line pipe as casing resulting in an excellent saving. Very good results can be obtained with the assurance of full strength in leak proof joints by welding casing with the backhand process of oxyacetylene welding where the time required for the job is not considered a handicap to the use of this method. Because of the heat applied by this method almost as much time is required for cooling of the weld after completion as is required for all the other operations of welding. A big advantage of oxyacetylene welding is that it permits use of salvaged and torch beveled pipe with plain butt welding.

The general practice of casing welding first became popular in the California fields, but due to the greater drilling activity there has been a greater use in the past year in the Midcontinent and Gulf Coast fields. More than three thousand strings of arc-welded casing have been run in these producing areas.

The most popular type of joint in casing welding is the bell and spigot joint because of ease of alignment and positive protection against penetration of the weld inside the joint. The plain and butt-welded joint has been used by Carter Oil Company because of tensile strength and the advantage of clearance offered by this type of joint. Description of the procedure followed with time and cost data is furnished by Mr. L. R. Hodell in his paper. It is expected that a satisfactory double bell and ring type of joint will be developed this year to combine the advantage of the tensile strength of butt welds with the protection from weld-metal penetration offered by the bell and spigot joint.

Specially trained and qualified welders are required on casing welding. The principles of pipe welding are the same as on the welding of pipe lines, but to insure a consistent high quality of welds the welders must have sufficient training to be experienced in welding in the positions required. This training may be gained on the welding of conductor type or by a term of practice on joints similar to that of the casing and in the same position as the welding will be done in the rig.

A subcommittee of its general pipe committee was appointed by the American Petroleum Institute at its last annual meeting to gather information on and provide standards for the welding of casing. Chairman of this committee is Mr. L. R. Hodell of Carter Oil Company. At its first meeting this committee recommended that casing welding is a contractor's job since it requires the maintenance of a group of specially trained welders. Before casing welding will become general practice there must be established contractors for this work easily available to the producers where drilling is active. Such service is readily available in the East Texas and Texas Gulf Coast fields, and it is expected that it will be extended into the Oklahoma and Kansas fields this year.

All of the operations of running welded casing are similar to the running of threaded-and-coupled casing, excepting the operation of alignment of pipe ends and the operation of welding. Two or more welders work together on each joint to reduce welding time. The number of welders employed depends on the size of the pipe and the advantage in cost gained.

Using the oxyacetylene process, the casing string is supported by slips with the joint to be welded at a convenient level little above waist-high. Two or more welders complete the weld with a backhand procedure. From three to five minutes is required for cooling before the joint can be loaded, the casing raised from the slips, and the casing string lowered into position for the next weld.

In the arc welding of bell and spigot pipe of nine and five-eighths inches in diameter the common practice is to employ two welders. The welders after tacking start on opposite sides of the pipe between tacks and complete a two-bead well in a complete circuit around the pipe

with continuous welding. As each welder reaches the starting point of the other with his first or stringer bead, he continues on with a larger diameter electrode overlapping the stringer bead of the other welder with his filler bead and without scaling of the stringer bead. On $13^3/_8$ inches and larger casing, three or more welders work simultaneously, starting at points equally spaced around the circumference of the joint. Each welder covers his own stringer bead with the filler bead using larger diameter electrode and without scaling. Thirty seconds is allowed after completion of welding for the weld to cool before it is loaded by picking up the string from the slips and lowering into position for the next joint. Running casing averaging in length forty feet per joint with this procedure, the time required for running welded casing will approach very closely the time for running threaded-and-coupled casing of similar size.

On the arc welding of casing strings of bell and spigot pipe of 7 inches and smaller diameter of oil strings of 6000 feet and longer, the customary practice is to use two welders, each welding half of the joint and working on opposite sides. Three beads are run, scaling after each bead. The time required for making the three bead weld is reduced by quenching with a cold water spray on the pipe above the weld after the second and third bead. All who are interested are not in agreement as to the procedure for the welding of the smaller size and longer oil strings. A number of changes will be made in the welding procedure to insure consistent weld strength and ductility without penalty of additional time requirement for running the welded casing.

On casing larger than $13^3/_8$ it is customary to use three welders on each joint. Where time is an important factor more welders may be employed, but it is the experience of welding contractors that welding cost will be greater. In some cases additional welding cost will be offset by a reduction of total rig time in running the strings.

The greatest objection to the use of welded casing is that the time required is greater than the time required for running threaded and coupled casing of similar sizes. Where casing is being set through caving formations the additional time adds to the hazard of getting the casing stuck before it is landed on the bottom. Part of this hazard is reduced by the fact that strings with welded joints can be worked in the hole without damage to the joints. Up to this time practically all of the thought devoted to casing welding has been on the training of welding personnel and development of welding procedure. A great deal can be done to increase the speed of running welded casing by adaptation of the other operations in the rig to the running of welded strings. Thought is being given to suitable operation in the handling of the pipe to permit handling of eighty foot lengths, thus cutting the number of welds required in half which should give welded casing the advantage over threaded-and-coupled casing in total running time.

On oxyacetylene welding of casing the equipment used is the same as used for welding pipe lines. On arc welding standard portable gasoline-driven welding generators of three hundred amperes capacity are generally used. To insure against any delay resulting from machine trouble an extra welding generator is carried to the job for a standby. The welding generators are mounted either three on a large truck or two on a smaller truck for movement to the well location. Where the smaller truck is used with two generators, the third or standby generator, may be mounted on a pick-up truck.

It has been predicted that when a casing welding service is developed, as easily available to all fields as the service of a well-known oil well cementing organization, welding of the major part of the oil-well casing will be universal.

It is a little early in the experience of casing welding to predict the rate of progress of this development or to name standards for welding procedure, tools or materials. The welded joint has the advantage of economy over other types of joints on pipes of all sizes and in all lengths of casing strings. Many successfully completed welded casing strings have proved their quality for acceptance as a practice by the oil and gas industry. Development must be along the line of speeding up the completed job without any loss of quality in the welded joint.

# USE of WELDING in RECONDITIONING Used Cars*

By T. W. MOSS†

WELDING has become a paramount factor in the manufacturing of automobiles. Without the modern welding facilities of today, cars, and particularly the bodies, could not be built with the present day style, safety and durability.

Adequate methods and facilities for electric arc and gas welding are equally important in servicing and reconditioning the cars of today.

What do we mean by reconditioning used cars? A reconditioned car is one that has, as nearly as possible, been restored to its original appearance and performance.

Used car reconditioning started when the first used car was traded back to a dealer as part payment for a new car as the dealer was forced to recognize the importance of restoring the original appearance and performance in order to resell it at a satisfactory price. In the days of wooden and composite bodies, the dealer had to depend largely on carriage and blacksmith shops for body and sheet metal repairs. It was very difficult for a dealer to completely restore the original appearance of a car that had been damaged by accident or had deteriorated from natural causes, without renewing the body and sheet metal which, in most cases, was prohibited by cost. Unsightly repairs often resulted even with the best available equipment and workmanship and although the dealer spent considerable money in improving the performance of the car it was not always a salable piece of merchandise because of its appearance.

The necessity for having adequate reconditioning facilities became more apparent as new car sales grew and the number of cars traded back to dealers increased.

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At the same time the demand for repair facilities increased as the purchasers of both new and used cars began to charge the dealer who sold the cars with the responsibility of making available repair parts and trained workmen to keep their cars in satisfactory operating condition.

So we see that the reconditioning of the cars traded in for resale and the repairing or maintaining of cars while they are in the hands of owners requires the same tools, equipment, trained workmen and parts. Reconditioning work being performed after the car becomes the property of the dealer, while service or maintenance work is performed for the car owner.

The principal difference, however, is in the matter of expense. Here the dealer becomes vitally interested in reconditioning facilities that will permit him to reduce both time and expense to the lowest possible figure. Time because competitive conditions require that the car be resold in the same market in which it was purchased, and expense, of course, because it affects the selling price of the car. Both of these factors, however, materially affect the possibility of resale at a satisfactory price.

Although good service facilities must be provided at reasonable prices the control of used car reconditioning is uppermost in the minds of car dealers today, to the end that many large dealerships have established separate reconditioning and service shops in an attempt to secure more efficient operation of both departments.

All-steel bodies and sheet metal are largely responsible for the appearance of the car, and with the modern welding and painting equipment it is possible for a dealer with a reasonable amount of equipment to practically restore the original appearance of the car. The chassis have been simplified, personnel educated, and service tools and equipment developed to a point where it is possible also for dealers to restore the original performance of a car. A car which has both the original appearance and performance restored can be considered a reconditioned car.

Here are the operations performed on the average used car by dealers using modern reconditioning methods:

1. The exterior of the car body, fenders, top, running gear and motor are thoroughly cleaned with modern steam and chemical cleaners. This removes all grease and dirt and leaves all surfaces ready to work on.
2. Work required to restore the original performance of the engine, clutch, brakes and other units of the car is then performed.
3. Next, the needed sheet metal repairs are made—dents removed from body panels, fenders, splash aprons, etc. Torn fenders are welded and reinforcements added, braces heated and straightened, frames repaired, etc.
   In this phase welding equipment of all kinds plays an important part. It is truly the magic wand that permits many parts to be repaired, joined or straightened, which could not be replaced or repaired by other methods as satisfactorily and economically.
4. After the sheet metal parts are straightened and repaired the welds and small dents are solder filled and the surfaces prepared for painting, using power bumping and sanding equipment.
5. Rust spots are removed, bare metal surfaces primed, and the remainder of the exterior surfaces prepared for painting. This includes the masking of all glass, bright metal parts, such as door handles, bumpers, etc.
6. The first finish coats are then sprayed on the car, using modern spraying equipment. Primers and surfacers are applied first, followed by the color coats. Modern quick drying automobile finishes permit this work to be done quickly and at the same time provide a beautiful, durable finish.
7. The interior of the car, cushions, headlining, etc. is next cleaned with a powerful vacuum cleaner. If necessary, the trim is scrubbed with a mild soap and water solution as modern vacuum cleaners have sufficient suction to remove all of the cleaning solution, preventing any possibility of mildew or mold and leaving the interior of the car clean and fresh.
8. While these operations have been taking place the battery and tires have been removed. Batteries are recharged or replaced as necessary. Tire treads are regrooved or tires replaced if worn to the point where replacement is advisable.

This brief outline shows that proper used car reconditioning can restore the appearance and performance of a car when properly and systematically carried out.

It has, however become more involved as sales and competition have increased and is today a very important dealer activity. Acetylene welding equipment is recognized by most dealers as essential to their service and used car reconditioning departments, as this type of equipment is used for welding, soldering, repairing bodies and sheet metal, and for welding and straightening many chassis parts. Electric arc welding equipment is used by some dealers on certain types of body and sheet metal work, particularly where the flame of a torch would damage a larger area of finish, or necessitate removing additional upholstery.

As a factory service division we are fully aware of our responsibility in seeing that the automobiles built by our company are properly and economically maintained for the original buyers, and that the dealers taking the cars in trade are able to, as nearly as possible, restore the original appearance and performance in order that the cars can be resold to advantage and will still be a credit to the names they bear.

We know the job cannot be done without adequate welding facilities. Therefore, we are continuously advocating that our dealers equip their shops with adequate welding equipment. Our recommendations in connection with all such equipment are confined strictly to adequacy, the type and make being left entirely to the dealer's own choice and judgment.

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# MACHINE FLAME CUTTING with Small Machine*

By OTTO C. VOSS†

OXYACETYLENE cutting in this day is a highly developed art. There can be no doubt that it has been one of the main factors in bringing electric welding to its high stage of adaptability. Foremost in the field of cutting is the automatic or semi-automatic machines carrying one or several torches producing single or multiple cuts.

There are several machines on the market at the present time which are capable of producing cuts of high accuracy, but it is important to the purchaser that he select the machine which is best adapted for his work. For instance a multiple torch machine would be highly impractical for a job shop where perhaps one or two pieces of each size and shape are required.

There are two general ways of guiding the torch in the path required, either by hand manipulation over a traced path either on the plate to be cut or a layout, and by following a fixed track.

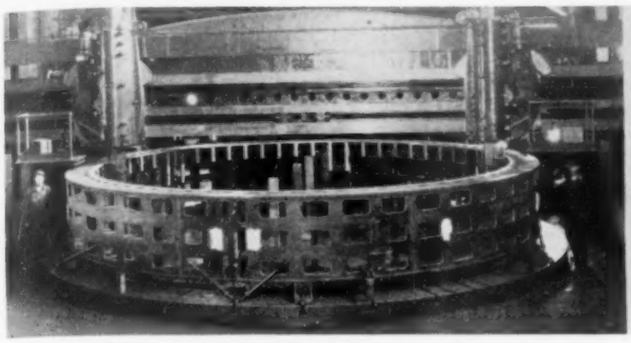
The first method requires skill on the part of the operator, the second, skill on the part of the man producing the track. Back of both methods, of course, lies the layout man who produces the original template from which the machine is guided or the track produced.

The layout man is the real key to the problems of producing cut shapes which can be assembled into a welded structure without further machining. In addition to

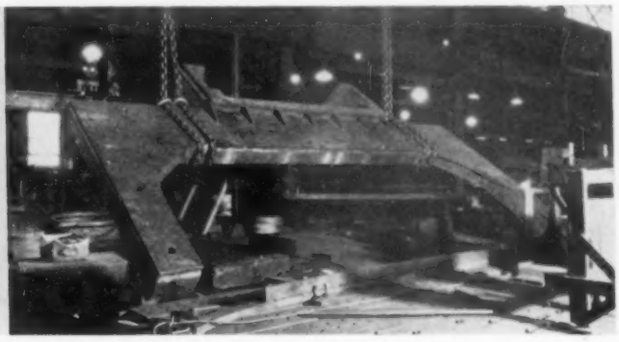
* Paper to be presented at Annual Meeting, A. W. S., Detroit, Mich., Oct. 16 to 21, 1938.

† Allis Chalmers Mfg. Co., Milwaukee, Wis.

Boring Yoke of 28,000 Kw., 3 ph., 94.7 R.P.M. Vertical Water Wheel Generator



Exhaust End and Generator Base Plate—115,000 Kw. Steam Turbine



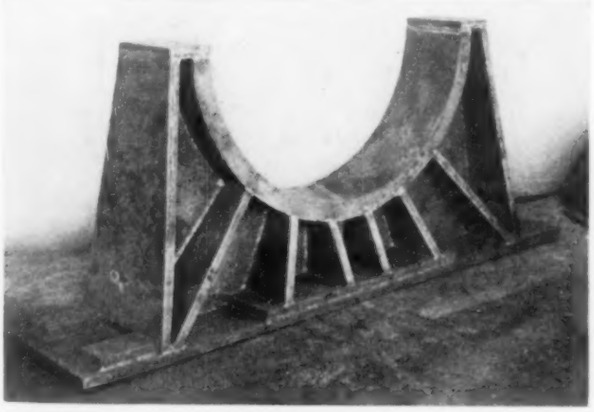
being able to reproduce into templates the parts shown on the prints he must also have knowledge of the welding procedure, technique, shrinkage, etc.

The machine operator is also an important factor in the cutting of plates to small tolerances. He must, in the first place, keep his torch or torches clean so as to produce the cuts free from irregularities. Second, he must have knowledge of the proper size torch and gas pressures to use on each plate thickness. And third, he must be able to adjust his torch to the correct angles, speeds, etc.

A shop equipped then with proper machines and personnel should be able to make use of the oxyacetylene process to the highest degree. A great many jobs can be produced with very little machining or other shaping before the welding process. Housings, frames, bases and structures of similar design can be easily adapted to this type of work.

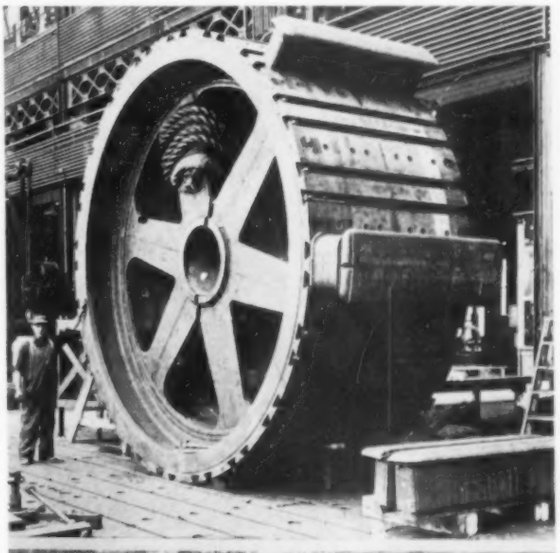
One of the greatest fields of use for the small cutting machine is the cutting of flanges, covers, rings, levers, etc., which can be machined without further work. A great deal of time is saved where the job must be delivered in a hurry and the saving over a casting where the pattern cost involved is considerable.

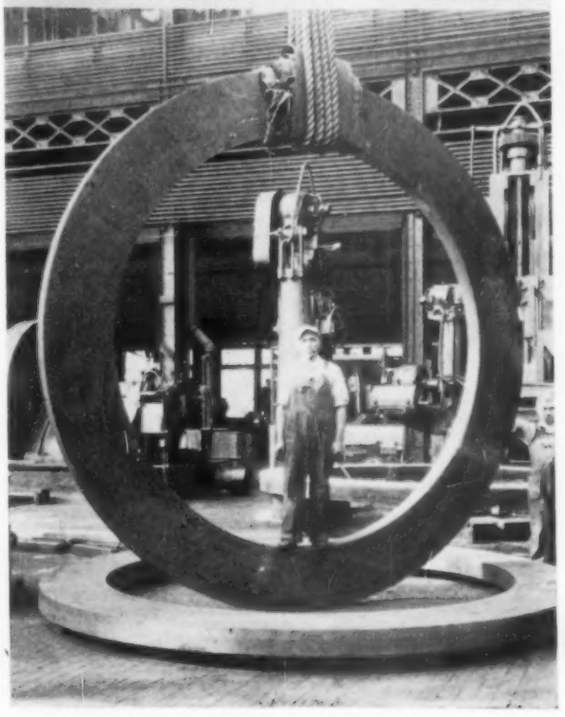
In our own shops we have produced practically an infinite number of structures, both simple and complex over a period of years. They range from simple detail parts to large welded assemblies weighing 40 to 50 tons. In fabricating them we have used plates varying from $^1/_8$ to 14 inches in thickness. Most of our work has to be machined in the final processes of manufacture, and is therefore held to very close tolerances averaging around $^1/_4$ inch. However, we have found oxyacetylene cut material perfectly capable of meeting the requirements of all work in this line.



8 Feet 0 Inch Ball Pot Mill—Welded Steel Base for 30-Inch Timken Roller Bearing

Rotor Spider with Field Coil and Pole of 32,500 Kva., 150 R.P.M., 25-Volt Generator





Spider Ring of Boulder Dam Generator

# Welding Society ACTIVITIES — Related Events

## A MESSAGE FROM OUR PRESIDENT

To the Members of the
AMERICAN WELDING SOCIETY:

As the date of our Annual Meeting at Detroit approaches, and my term as President of the Society draws to a conclusion, I look forward with happy anticipation to a full reunion of our officers and personnel at Detroit, and to forming or renewing acquaintance with those whose labors have made possible the material progress which we have witnessed within the past year.

The plans for our Nineteenth Annual Meeting, which will be held in conjunction with the Metal Congress and Exposition, are now complete; each member of the Society has been furnished with a detail program. Through the activity of our Program Committee a series of outstanding papers has been made available. The number of these papers represents an increase of forty per cent over those presented at the 1937 meeting, and we are confident that, in the varied fields of discussion represented, each of our members can find something of interest and profit to make his visit to Detroit worth while. Another object of these Annual Meetings is the informal exchange of ideas and information, representing the fruits of experience acquired during the preceding year. The actual value of a single item of information thus obtained may represent many times the cost of attendance.

P. G. Lang Jr.

On these occasions the elective offices of the Society ordinarily pass into new hands, and the business meeting for the transaction of essential matters occurs. At the Detroit gathering the Business Meeting is scheduled for the Final Session, instead of at the beginning. It is hoped that all attending members will so arrange their plans as to remain until the final day, and encourage the incoming President by their presence. As your retiring President it is to be my duty and pleasure to render an account of my stewardship.

Also, the value and importance of the social feature should not be overlooked. As practitioners of a common art and science, we should seek to know each other in the social as well as the professional character, and to extend the bond of union and friendship. To this end, I wish to express the sincere hope that our members will, on this occasion, be accompanied by their families. Our program has been formulated with due regard to the interests of the ladies, and to them also the City of Detroit offers a most attractive field for diversified recreation.

Those interested in the welfare of the AMERICAN WELDING SOCIETY may regard the material accomplishments of the past year with profound satisfaction. As a result of our promotional efforts and of the expanding interest in welding, our membership has undergone an increase of 50 per cent, and new local sections have been established in many large centers. The 1200-page Welding Handbook, which has been in course of preparation for the past few years, and represents the collaboration of approximately 350 outstanding experts in this field, working in conjunction with our Editorial Committee, has been published, and has already been widely distributed. The codes and specifications originated by the Society, including its Bridge and Building Specifications, and Codes for Qualifications of Operators, Material and Equipment, have acquired increased recognition as the country's standards. Industry is supporting a comprehensive program of research under the auspices of the Society, which confirms its position as one of the outstanding organizations in this field.

Thus, we may look backward upon a year of accomplishment, and forward to a happy reunion at Detroit, followed by a twelvemonth of accelerated progress. Our incoming President, Mr. H. C. Boardman, has already given ample proof of his devotion to the interests of the Society, and his capacity for constructive activity. His labors as Chairman of our Committee on Outline of Work have been of inestimable value. I am confident that his Presidency will be characterized by activity and progress in every field, and, on my own part, I wish to assure him of my desire to cooperate in any manner possible to make his administration an era of unprecedented accomplishment. This sentiment, I have no doubt, is shared throughout the personnel of the Society.

It is a matter of profound regret that I shall probably be unable to personally greet and thank each of those to whose efforts the Society's progress during the past year has been due. I wish, however, at this time, to make a general acknowledgment of my debt and that of the Society to these willing and efficient coworkers, to express the hope that each of you will have a most happy and profitable visit to Detroit, and that, during the succeeding year, you will accord to Mr. Boardman a continuation of the loyal and effective support with which you have favored me.

P. G. LANG, JR.

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## NATIONAL METAL EXPOSITION AND CONGRESS

The third week of October will be a busy and interesting one for members of the American Society for Metals, judged by the tentative technical program just announced for the annual convention.

The program will get off to a fast start on Monday, October 17th, with two simultaneous morning sessions and before the week is ended forty-nine lectures by some seventy-six authors will have been presented.

Two educational courses will be among the features of the program. One course begining at 4:30 each afternoon of the week will take up machinability of steels and nonferrous metals, while the other, to be delivered at 8 p.m. on Monday, Tuesday and Wednesday, will be on pyrometry.

Government, college and industry are well represented among the seventy-six men who have devoted a great deal of research during the past year to this program.

The program itself is part of the attraction that will bring 10,000 metal men to the National Metal Congress and Exposition this third week of October.

The Exposition and afternoon technical sessions will be held in the Convention Hall, Detroit. The Exposition is already far larger than last year's show, with more than 230 leading companies taking space as exhibitors.

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## INTERNATIONAL ACETYLENE ASSOCIATION MEETING

International Acetylene Association has decided to hold its next convention in the spring of 1939 instead of this fall.

In so doing it expects to give those interested in welding and its allied subjects an opportunity to attend without conflicting with their attendance at the meetings of other associations whose activities are related.

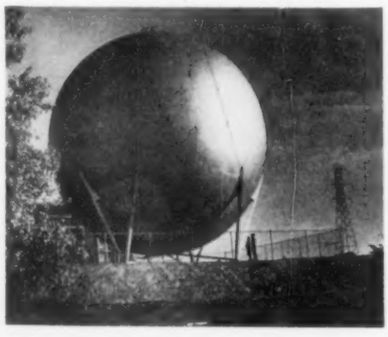
## WELDED ERECTION SEATS

A very interesting pamphlet on the subject "Erection of Welded Structural Frames by Welded Erection Seats," has been prepared by Mr. Van Rensselaer P. Saxe, Consulting Civil Engineer, 100 W. Monument Street, Baltimore, Md. This folder contains pertinent engineering and illustrative data.

## COMBUSTIBLE GAS FROM DECOMPOSED SEWAGE TO BE STORED IN NEW WATERLESS TYPE HOLDER

A pressure gas holder (see illustration), a comparatively new type for storing gases generated by decomposition of sewage, has been completed at the Cuyahoga Heights southerly plant of the $14,000,000 sewage disposal project of the City of Cleveland, Ohio.

The holder is a 57½ foot diameter arc-welded sphere having a capacity of 200,000 cu. ft. of free gas at 29 pounds operating pressure. The design and method of construction made it possible to obtain the required capacity in a structure which is considerably smaller than would be the case with other types of holders. The smaller size provides savings, not only in initial cost, but also in operating costs, since there are no moving parts. Maintenance costs are expected to be negligible.



**Like a Bubble, This Structure Has Uniform Stress in Every Part. It Is an Arc-Welded Pressure Gas Holder Recently Completed at Cleveland, Ohio in a $14,000,000 Sewage Disposal Project**

The purpose of the holder is to store gas produced in excess of normal consumption and to pay out deficiencies as required. The sphere floats on the line in much the same manner as an elevated tank in a water system. The surplus gas in the sphere will be compressed and paid out into the service lines as needed for laboratory, boilers and two 400 horsepower gas engines. In normal operation of the plant, with the sphere off the line, gas is generated at a pressure of approximately 20 inches of water which is sufficient to supply the engines and boilers. Generation of gas is by natural decomposition, accelerated by controlled digestive elements.

The designers of the disposal project, George B. Gascoigne and associates, Cleveland, liken the sphere's form to a bubble, nature's example of a structure having uniform stress in every part.

The holder was fabricated by the Chicago Bridge & Iron Company, Chicago, Illinois by welding, using shielded arc type electrodes.

In constructing the sphere, steel plate was cut and formed in such a way as to provide the desired shape when the pieces were assembled together. Plate edges were scarfed to assure complete penetration of welds. All joints, were butt welded from both sides. Where more than one bead of weld-metal was applied, each bead was scraped, wirebrushed and peened before application of the next.

All welders employed in construction of the holder were qualified in accordance with the U-69 qualification tests of the A. S. M. E. code for unfired pressure vessels.

When erection was completed, the holder was tested to a pressure of 45 pounds per sq. in. minimum, after all joints were coated with linseed oil.

## EVENING GRADUATE COURSES

Stevens Institute of Technology is offering for the first time during the academic year 1938–39 evening graduate courses for Engineers.

## NEW YORK SECTION LECTURE COURSE

A series of 12 lectures will be given by this section in cooperation with the Polytechnic Institute of Brooklyn, commencing November 22, 1938.

## XIII INTERNATIONAL ACETYLENE CONGRESS

The letter reproduced below has been received by the Technical Secretary. Anyone desiring to participate in this Congress should communicate with Mr. W. Spraragen promptly.

August 10, 1938

Dear Mr. Spraragen:

In July 1939 the Thirteenth International Acetylene Congress will be held in Munich. I have been asked by the General Secretary to take charge of the Division on Technical Testing of Welded Joints. Consequently I should like to invite you and the members of your Society to take part in this part of the Congress. At the same time I should like to know who among your Society is in a position to contribute papers on the Testing of Gas Welds and Gas Welded Structures. I will be much indebted to you if you will tell me the names and addresses of those possibly interested, and in what subject they will be interested so that I can correspond with them.

Yours truly,
(Signed) O. Graf

## WELDING DAM CONSTRUCTION

A new T.V.A. order for 18 spillway gates and one trash gate to be installed in the Chickamauga Dam on the Tennessee River has been awarded to Dravo Corporation, Pittsburgh, Pa. Each of the spillway gates will be composed of separate top and bottom sections, with the top structures measuring 41 feet wide and 20 feet high, and weighing about 40 tons. The heavier bottom sections, which will be subjected to the greater pressures, will be of similar width and height, but will weigh about 65 tons each. The trash gate will be composed of three sections.

Dravo furnished the recently installed gates for the Pickwick Landing Dam, and is now completing at its Engineering Works Division on Neville Island, the fabrication of spillway gates for the Guntersville Dam, another T.V.A. unit on the Tennessee. As was the case on these jobs, welded skin-plates—a new development in spillway gate construction—will be employed, but all other parts are to be riveted.

## STANDARDS CONFERENCE

At the conferences of the International Federation of National Standards Associations (ISA) in Berlin, June 17 to July 2, 1938, which were attended by representatives from 19 countries, Committee 44 on welding met for the first time. A total of 38 delegates attended. After a preliminary discussion the following subcommittees were formed:

| | |
|---|---|
| ISA 44/1 | Symbols and terms. |
| ISA 44/2 | Welding apparatus, materials, and accident prevention. |
| ISA 44/3 | General rules, preparation for welding, and technique of different welding processes. |
| ISA 44/4 | Base Metal and Filler Metal (Weldability, Heat Treatment, etc). |
| ISA 44/5 | Methods of Testing (mechanical, non-destructive, etc). |
| ISA 44/6 | Training, Testing, and Supervising the Welder. |
| ISA 44/7 | General rules and recommendations for the design of welded joints. |

These subcommittees will keep in touch with other subcommittees of ISA interested in welding. Committee 44 will also maintain contact with all international welding organizations.

## AMERICAN INSTITUTE OF STEEL CONSTRUCTION

Members of the AMERICAN WELDING SOCIETY are cordially invited to attend the Sixteenth Annual Convention of the American Institute of Steel Construction to be held October 11, 12, 13 and 14, 1938 at the French Lick Springs Hotel, French Lick, Indiana.

## WIRE ASSOCIATION MEETING

One of the organizations meeting in Detroit during the National Metal Congress and Exposition is the Wire Association which will hold its meeting on the 17th to 21st. A very interesting program

has been provided. Members of the Society may obtain copy of this program by writing to Mr. R. E. Brown, Secretary, The Wire Association, 17 East 42nd Street, New York, N. Y.

## SURELY HERE IS "ART" IN CUTTING

On November 5, 1871, west of Wickenburg, Arizona (now on highway U. S. 60), the Wickenburg-Ehrenburg stage was ambushed by Apache Mohave Indians and eight of its occupants massacred. To memorialize this gruesome happening and identify the locality involved, the Arizona Highway Department designed and erected a most attractive monument as here illustrated. The stage coach, driver and

*Photograph Courtesy of Victor Equipment Company*

horses were cut out of steel plate with a cutting torch, as was also the memorial tablet. The tablet, incidentally, was cut to simulate the Arizona state boundary lines. The letters were imposed upon the steel plate by arc welding, after which the entire tablet was sprayed with bronze paint. And so does welding and cutting play its part as well in the arts as it does in industry.

## LOUIS J. LARSON

Louis J. Larson having resigned his position with the A. O. Smith Corporation, has established a consulting engineering service on welding and related problems including the design for welding, a study of production methods, and the development of procedures for welding special alloys.

## NEW WELDING SCHOOL AT WESTINGHOUSE

Complete with the most modern equipment for D.C., A.C. and automatic welding the new welding school in the East Pittsburgh plant of the Westinghouse Electric & Manufacturing Company is designed to give thorough training to each student and inform him on the latest practices in the art of arc welding.

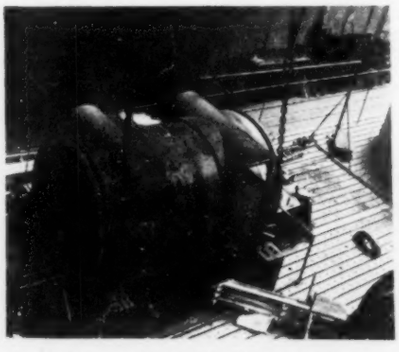
School begins the students' training with bare wire, which requires a high degree of skill. Therefore, the students' training begins with bare wire in order to emphasize fundamentals of good fusion and proper penetration, and develop skill in welding. After the student has received sufficient instruction with bare wire, training starts with coated wire.

Believing that the development of skill in manipulation of the arc is essential, each student is assigned an individual machine, which he uses throughout the course. Two instructors are on duty at all times so that each student has ample individual instruction and guidance.

Instruction is given in welding with direct current, alternating current transformer type welders and automatic welding equipment. Suitable lectures on theory and on care and operation of machines are included in the course.

The complete course consists of 200 hours. The average work week is 40 hours so that except for holidays interfering, the course is concluded in five weeks.

**Power Giant—New 50,000 Kw. Turbo-Generator Stator and Housing Built by the Westinghouse Electric & Manufacturing Company for the Schuylkill Power Station of the Philadelphia Electric Company, Being Lifted from**



**the Test Floor of the East Pittsburgh Westinghouse Works. The Two Horizontal Openings Are for the Water-Cooled Hydrogen Coolers Which Will Dissipate the Heat Generated as the Machine's Rotor Spins Around 3600 Times a Minute**

## NATIONAL SAFETY COUNCIL SILVER JUBILEE

The Silver Jubilee Safety Congress and Exposition sponsored by the National Safety Council will be held in Stevens Hotel, Chicago, Oct. 10 to 14, 1938 inclusive.

Members of the AMERICAN WELDING SOCIETY are cordially invited to attend these sessions.

## WELDING SAVES 30 TO 60% IN MANUFACTURE OF COMBUSTION EQUIPMENT

The construction of pulverizing and dust collecting systems is the principal interest of the Raymond Brothers Division of the Combustion Engineering Company, Chicago, Ill. Collector apparatus, ducts, coal pulverizers and cage mills are some of the basic equipment produced by this company which reports a saving of from 30 to 60 per cent in shop costs since adopting welding as a fabrication tool. Former methods of construction, which involved riveting, were not only slower and more expensive but entailed more complex designs. Moreover, welding produces equipment which is absolutely dust-tight.

**Operators Fabricating a Classifier for a Coal Pulverizer for the Southwest Sewage Treatment Works of the Sanitary District of Chicago Using a Multiple-Operator Constant-Potential Arc-Welding Equipment**

## JURY OF AWARD, AFTER JUDGING LINCOLN FOUNDATION PAPERS, FINDS $1,600,000,000 SAVINGS AVAILABLE TO INDUSTRY*

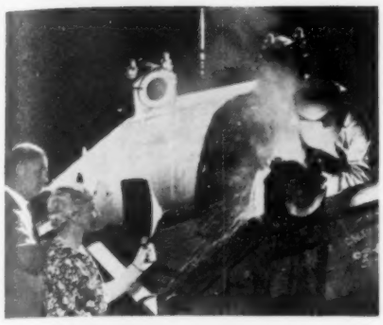
### 382 Awards in the $200,000 Foundation Program Made to Authors Throughout Industry

The Jury of Award of the James F. Lincoln Arc Welding Foundation, Cleveland, Ohio, after judging thousands of papers submitted in the $200,000 Award Program, found that savings to industry by arc welding claimed by authors of papers aggregates $1,600,000,000. The Jury's statement, released Sept. 15th at the conclusion of its judging of the papers, follows:

"The Central Committee of the Jury of Award of the James F. Lincoln Arc Welding Foundation finds that the savings to industry by arc welding claimed by authors of papers aggregates $1,600,000,000. This figure is arrived at after discounting some very enthusiastic claims. It is an amazing figure and undoubtedly would have been much greater had all of the authors estimated gross savings from the application of arc welding to their products."

Altogether, 382 awards were made by the Foundation. The amounts ranged from $101.75 for honorable mention to $13,941.33, the Grand Award. Recipients included engineers, designers, architects, production managers, superinten-

* A news release.



Mr. and Mrs. A. E. Gibson, President and Stockholder, Respectively, The Wellman Engineering Co., Cleveland, Ohio, Grand Award $13,941.33.

dents, draftsmen, shop foremen, mechanics, inspectors, welding operators, welding supervisors, owners of businesses, college professors, high school instructors, students and others. Subjects of studies in the 44 divisions of the Program, represented practically every product and structure of industry.

The Grand Award of the Program, $13,941.33, went to Mr. and Mrs. A. E. Gibson, president and stockholder, respectively, The Wellman Engineering Co., Cleveland, Ohio. The paper, "Commercial Weldery," entered in the Welderies Classification of the Program, is an outstanding treatise on all the elements required to assure the business and technical success of all users of welding throughout industry.

An award of $11,397.06 was received by Anant H. Pandya and R. J. Fowler, engineers, Diagrid Structures, Ltd., London, England. Their paper "The All Welded Grid Applied to Plane and Spatial Structures" will doubtless usher in a new era in the design of framing for roofs and floors of buildings. Eliminating trusses and columns except at corners of bays, the design makes a saving of $60,000,000 available to industry, according to the authors.

An award of $8852.94 was paid to Robert E. Kinkead, consulting engineer, welding, The Carnegie Illinois Steel Corp., Cleveland, Ohio, for his paper, "Industrial Machinery, Steel Making" in which he describes the use of carbon arc welding in a method of producing clad metals which if adopted, would save industry $9845,401 annually.

Award of $7326.46 went to L. J. Carey and Marvin Whitlock, foreman and engineer, respectively, American Air Lines, Inc., Chicago, Ill., for their paper "Welded Aircraft Piping." The study shows a new stride forward in an industry not so familiar with arc welding as with other forms. Savings in cost as well as increased safety and comfort of air travel are attributed by the authors to their design utilizing arc welding.

The other 378 awards were spread over the 11 classifications of the Award Program.

In the Automotive Classification, a total of $14,957.93 was awarded in the 4 divisions—engines, bodies, frames and trailers. The first award of $3764.94 went to H. C. Wendt, chief engineer, Hackney Bros. Body Co., Wilson, N. C., for his paper "Welded School Bus Body" which indicates a saving of 50% in cost through arc welding. Second award of $2543.88 was received by Fred S. Beach, Sr., designing engineer, Northwestern Electric Co., Portland, Ore. Third award, $1729.84 went to C. A. Davis, Jr., engineer, Caterpillar Tractor Co., East Peoria, Ill., and fourth, $1526.33, to Nelson Severinghaus, superintendent, Consolidated Quarries Corp., Lithonia, Ga.

Aircraft awards totaled $13,787.90, there being 10 awards. The largest for a paper in the classification was $7326.46, awarded to L. J. Carey and Marvin Whitlock. In addition to receiving first award in the Aircraft class, Messrs. Carey and Whitlock received Fourth Grand Award of the Program. An award of $1322.82 went to Ralph H. Upson, consulting engineer, Kay Products Co., Detroit, Mich., for his paper "Arc Welding in Aircraft." An award of $1017.56 was made jointly to James W. Fitch and John Czarniecki, engineers, Kenworth Motor Truck Corp., Seattle, Wash., for their paper "Beaching Gears for Aircraft." Seven other awards were made for papers in the classification.

Authors of papers in the Railroad Classification received a total of $13,736.90 for studies of arc welding applied to locomotives, freight cars, passenger cars, or locomotive and car parts, the 4 divisions of the class.

An award of $2543.88 went to John H. Hruska, metallurgical engineer, Electro-Motive Corp., La Grange, Ill., for his paper "Welded Body of Diesel Locomotives." Clyde B. Faverty, chief engineer, the Ryan Car Co., Chicago, Ill., and Ralph H. Redline, welding supervisor, American Locomotive Co., Dunkirk, N. Y., received $1526.33 and $1322.82, respectively. Fourteen additional awards were made in the classification.

Awards totaling $12,210.53 were made to authors in the Watercraft Classification J. T. Dalcher, consulting engineer, New York City, received $2543.88 for "Modern Type Welded Deck Barge." Stanley A. Midnight, structural designer, hull department, American Shipbuilding Co., Cleveland, Ohio, received $1322.82. An award of $1017.56 went to Robert H. Macy, member hull technical department, Newport News Shipbuilding and Dry Dock Co., Newport News, Va. There were 22 additional awards for papers on welded designs of commercial or pleasure craft.

Seventy-one authors received awards totaling $26,049.55 for studies of arc welding applied to subjects covered by

**Authors of Papers Receiving Principal Awards in Lincoln Foundation Program**

L. J. Carey, Foreman, American Air Lines, Inc., Chicago, Ill., Award $7326.46 Jointly with Marvin Whitlock, Engineer, American Air Lines, Inc.

Marvin Whitlock, Engineer, American Air Lines, Inc., Chicago, Ill., Award $7326.46 Jointly with L. J. Carey, Foreman, American Air Lines, Inc.

Robert E. Kinkead, Consulting Engineer, Welding, the Carnegie Illinois Steel Corp., Cleveland, Ohio, Award $8852.94.

the 4 divisions of the Structural Classification—buildings, bridges, houses and miscellaneous structures. Robert V. Proctor, general manager and chief engineer, Commercial Shearing and Stamping Co., Youngstown, Ohio, was awarded $2747.39 for his paper "Arc Welded Tunnel Liner" which shows that $15,198,907 could be saved on proposed tunnels. Messrs. Howard E. Boath and Charles MacNish, Corps. of Engineers, U. S. Army, St. Louis, Mo., received $1526.33 jointly as co-authors. A joint award of $1526.33 also went to Robert S. Treat and John F. Willis, Connecticut State Highway Department, Hartford, Conn.

Awards in the Furniture and Fixtures Classification, covering house and office furniture, totaled $10,684.28. An award of $3764.94 went to E. J. Freeman, associate professor, Clemson College, Clemson, S. C., for "Welded Lecture Room Chair." Paul J. Birkmeyer, New York City; Clinton Bolin, Lloyd Mfg. Co., Monominee, Mich., and Richard E. Drover, Illinois, Austin Co., Chicago, Ill., received $2543.88, $1729.84 and $1119.31, respectively. Six additional awards were made in the classification.

In the Commercial Welding Classification, the total amount awarded was $11,549.14 in the two divisions—one covering job shops, the other garages. An award of $3764.94 was made jointly to Howard E. McCord and Fred H. Drewes, W. G. Jarrell Mfg. Co., Charlotte, N. C., for their paper, "Organizing and Operating a Commercial Welding Shop." Awards of $2543.88, $1526.33 and $1322.82 went repectively to James M. Pool, Louisville Welding Works, Louisville, Ky.; E. W. Weinberger, owner, Weinberger Garage, Mott, N. D.; and George P. Harber, owner, Harber Engineering Works, Albany, Ore. Additional awards in the classification were sixteen.

The Containers Classification, covering containers, contents stationary (tanks, etc.,) and containers, contents moving (pipe lines, etc.,) accounted for $12,719.28 of awards. The largest individual amount in the class, an award of $3764.94, went to Arnold A. Seipel, hydraulic and mechanical engineer, Bureau of Reclamation, Denver, Colo. His paper, "Welded Scroll Cases for Hydraulic Turbines," showed a saving of $495,753.12 on 18 cases by use of arc-welded construction. Awards of $2543.88 and $1729.84 went to G. M. Stearns, district production engineer, Cities Service Oil Co., Russell, Kans., and Thomas S. Gaylord, supervisor of welding, Eastman Kodak Co., Rochester, N. Y., respectively. Other awards in the class totaled twenty-seven.

Awards in the Welderies Classification, in which the paper for which the author received the Grand Award of the Program was submitted, totaled $22,081.67. In addition to the first award of the class which went to the Gibsons, $1526.33 went to Paul H. Setzler, production manager, Lukenweld, Inc., Coatesville, Pa., and $1322.82 to A. H. Davison, engineer, U. S. Engineers, Providence, R. I., 21 authors received awards.

The Functional Machinery Classification, open to design studies of arc welding applied to machinery used in several industries, accounted for $28,592.83 of awards spread over the 10 divisions of the class—metal, cutting, metal-forming, electrical, prime movers, conveying, pumping and compressing, business, machinery not otherwise classified, jigs and fixtures and machine parts. The principal award, $3764.94, was received by John Mikulak, mechanical engineer, Electric Machinery Mfg. Co., Minneapolis, Minn. His paper was, "Design for Vertical Synchronous Motor." Awards of $1526.33 went jointly to co-authors L. M. Davis and J. M. Mousson of Baltimore, Md. and individually to John N. Anderson, designing engineer, Otis Elevator Co., New York, N. Y. Eighty-three additional awards were made in the classification.

The industry Machinery Classification produced the paper for which the author, Robert E. Kinkead received third Grand Award of the Program, also receiving first award in the class industry Machinery. This award is previously discussed.

Second award in the class, $2747.39, went to J. O. Bishop, master mechanic and welding supervisor, The National Supply Co., Torrance, Calif. Awards of $1526.33 went to Edmund G. Grant, California Institute of Technology and jointly to co-authors R. F. Bergmann, Rayon Machinery Corp., Cleveland, and A. F. MacDonald, American Bridge Co., Pittsburgh, Pa. The Industry Machinery Classification, open to design studies of arc welding applied to machines used exclusively in one of the industries covered by the class, accounted for the largest number of awards (79) and the largest amount ($33,629.99).

The Foundation's Award Program, which began 18 months ago, was judged by 31 engineering authorities from leading universities and colleges throughout the country, and has been hailed by leaders in science, education and industry as a valuable contribution to industrial progress in America.

# SECTION ACTIVITIES

## CLEVELAND

The following is the list of Educational Lectures to be given by Mr. John Kincaid of Wellman Engineering Company at Bingham Hall, Case School of Applied Science, 8:00 P.M.

Title of the Course—"Preparation and Interpretation of Drawings for Welded Designs"

October 25, 1938, Part I—"How Standard Welds Can be Shown"

November 1, 1938, Part II—"How Welds Should be Shown on Drawings"

November 8, 1938, Part III—"How to Select, Show and Know the Type of Weld for Various Joints"

November 15, 1938, Part IV—"How to Select, Show and Know the Type of Weld for Various Joints" (contd.)

November 22, 1938, Part V—"How to Prepare and Read Structural Drawings for Welds"

November 29, 1938, Part VI—"How to Prepare and Read Mechanical Drawings for Welding"

The following are the subjects and speakers for 1938-39 Meetings of the Cleveland Section:

Dinner Meeting—Cleveland Club 6:30, Oct. 5, 1938, "Welding in the Steel Industry," by Bob Kinkead.

Meeting—Bingham Hall, Case School of Applied Science, Nov. 9, 1938, "Single Pass Electric Welding of Unfired Pressure Vessels," by R. M. Wallace.

Dinner Meeting—Cleveland Club 6:30, Dec. 14, 1938. "Impact Testing of Welded Structures," by Leon C. Bibber.

Meeting—Bingham Hall, Case School of Applied Science, Jan 11. 1939, "New Developments in Cutting and Flame Hardening," by George V. Slottman.

Dinner Meeting—Cleveland Club 6:30, Feb. 7, 1939, "Large Welded Tanks of Cylindrical, Spherical and Spheroidal Shapes," by H. C. Boardman.

Meeting—Bingham Hall, Case School of Applied Science, March 8, 1939, "Welding Design on Main Avenue Bridge," by Fred L. Plummer.

Dinner Meeting—Cleveland Club 6:30, April 12, 1939, "Resistance Welding, It's Fundamentals and Practical Application," by Grover Hughes.

Meeting—Bingham Hall, Case School of Applied Science, May 10, 1939, "Metallurgical Factors which Determine Weldability," by J. C. Hodge.

The following Committee Chairmen and Officers constitute the Executive Committee of the Cleveland Section along with Past Chairmen E. R. Benedict and Gordon T. Williams

Chairman—Fred L. Plummer
Vice-Chairman—E. T. Scott
Secretary-Treasurer—A. L. Pfeil
Finance Committee—E. T. Scott
Program Committee—W. C. Heinle
Publicity Committee—C. T. Elder
Educational Committee—George G. Lambis
Membership Committee—L. H. Frost.
Nominating Committee—E. R. Benedict.

## COLUMBUS

At the regular meeting of the Columbus Section, Mr. E. W. P. Smith, Consulting Engineer of the Lincoln Electric Company, gave a very interesting and instructive talk on "Designing for Welding," after which the Chairman, Mr. Rickly announced that Mr. Emig had requested that he be released from his duties as Secretary and Treasurer. This request was granted and Geo. S. Herren of The Seagrave Corporation was duly elected to serve in that capacity for the ensuing year

## INDIANAPOLIS

An outing for the whole family was held by the Indianapolis Section on Saturday,

September 17th at Forest Park, Noblesville. Free dinner and free beer were the main attraction along with entertainment for the children of pony rides, soft ball, horseshoes and a golf course for the adults. A Big Day was enjoyed by all.

### KANSAS CITY

A dinner meeting was held at the Ambassador Hotel Roof Garden on September 19th. The dinner was followed by the regular meeting at which Mr. George L. Wiley, Supervisor of Welding for Mid-Continent Petroleum Co., was the guest speaker. Mr. Wiley addressed the gathering on "The Three Essentials of Welding—Engineering, Education and Enforcement."

### MARYLAND

At the November 18th meeting to be held at 6 W. Fayette St., Engineers' Club, Baltimore, Doctor G. A. Slottman will be the speaker and his topic will be "Gases Used in Welding and Burning."

There will be an Oyster Roast on October 29th at which the finest Chesapeake Bay Oysters will be served, with choice beverages.

### NEW YORK

On September 7th an inspection trip was made to the all-welded New York Telephone Company building which has just been completed. This building has an all-welded steel frame weighing 450 tons and is seven stories in height. The Section was fortunate in securing as speakers, to describe the welding procedure, men who were connected with the actual planning and erection of this building, one of the first all-welded structures erected since the adoption of the new building code. Speakers included Albion N. Van Vleck, First Deputy Commissioner of Housing and Buildings, Richard A. Backus, Associate, Voorheen, Gmelin and Walker, and Gilbert D. Fish, Consulting Engineer.

### MONTANA

Mr. Charles F. Garman has resigned as Secretary of the Montana Section. For the time being Mr. T. B. Jefferson of 620 Musselshell, Fort Peck, Montana, is acting as Secretary.

### PHILADELPHIA

The regular monthly meeting of the Philadelphia Section was held at the Engineers' Club, Monday, September 19th. Mr. H. C. Boardman of the Chicago Bridge & Iron Company, spoke on the subject "Large Welded Tanks of Cylindrical, Spherical and Spheroidal Shapes."

The following is the program of the Philadelphia Section for the coming season.

October 24, 1938—8:00 P.M.—Engineers' Club, Philadelphia, "Developments in Resistance Welding"

November 21, 1938—8:00 P.M.—Engineers' Club, Philadelphia, 'Stainless Steel Welding and Design"

January 16, 1939—8:00 P.M.—Engineers' Club, Philadelphia, "New Applications of Gas Welding"

February 20, 1939—8:00 P.M.—Engineers' Club, Philadelphia, "Structural Design and Welding"

March 20, 1939—8:00 P.M.—Engineers' Club, Philadelphia, "Residual Stresses"

April 17, 1939—8:00 P.M.—Engineers' Club, Philadelphia, "Steel Casting and Plate Fabrication"

(Joint Meeting with American Foundrymen's association)

May 1939—Place to be Announced

ANNUAL INSPECTION TRIP

The following is the Executive Committee for the 1938–39 season:

E. G. Hosted, Chairman
H. R. Salisbury, Vice-Chairman
R. D. Thomas, Treasurer
H. E. Hopkins, Secretary
T. M. Jackson, Past Junior Chairman

| | |
|---|---|
| T. A. Jones | W. S. Wagner |
| W. W. Barnes | John J. Dunne |
| J. A. Mitchell | C. I. MacGuffie |
| J. W. Allison | H. W. Lawson |

W. F. Carson

### ST. LOUIS

The plant of the Granite City Steel Company, Granite City, Illinois, was visited by over 300 members and guests of the St. Louis Section on Friday evening, September 9th, as the initial meeting of the 1938–39 season's activities.

The party was divided into groups of approximately twenty, each group was conducted through the large plant by an experienced employee and was shown the entire process of converting the raw materials into finished steel products.

The trip was extremely interesting and instructive and the courtesy extended the St. Louis Section by the Granite City Steel Company was appreciated by all.

### SAN FRANCISCO

The Executive Committee of the San Francisco Section held their first meeting on August 31st. Various matters, such as the policies for the coming year, programs for the ensuing meetings, etc., were discussed.

The September meeting was delayed one week until the 23rd. This meeting was featured with a display and demonstration by the Handy & Harman Company.

### WESTERN NEW YORK

The Western New York Section have appointed Mr. J. A. Fish as Chairman of their Membership Committee and Mr. W. B. Miller as Chairman of the Program Committee.

### WICHITA

A well-attended meeting with an attendance of 70 was held by the Wichita Section on August 26th. Mr. Roy Peterson, of the Peterson Welding Laboratories, read and explained a paper on "The Control of Expansion and Contraction by Local Heating in Cast Iron Parts." The paper as well as discussion proved very interesting and was well received.

An inspection trip to the plant of the Coleman Lamp & Stove Company was made on September 23rd. All types of welding is being done at this plant and production line work was in progress during the inspection.

### PROTECTING METALS AGAINST CORROSION

The American Society for Testing Materials, 260 South Broad Street, Philadelphia, Pa., has prepared a pamphlet comprising four technical papers presented at a meeting of the Detroit chapter of the A. S. T. M. on Protecting Metals Against Corrosion. This report consists of the following papers presented at this Symposium on "Corrosion-Resistant Alloys" by H. W. Gillett, Metallurgist, Battelle Memorial Institute, "Protection of Base Metals by the Use of Metallic Coatings" by C. E. Heussner, Materials Engineers, Chrysler Corp., "The Pre-Treatment of Metals" by R. J. Wirshing, Research Engineer, General Motors Corp. and a discussion on "Corrosion Protection by Means of Organic Coatings" by J. L. McCloud, Metallurgical Chemist, Ford Motor Co.

### FILLET WELDING ELECTRODE

Metal & Thermit Corporation, 120 Broadway, New York, N. Y., announces an addition to its line of Murex heavy coated electrodes for manual arc welding. The new electrode, known as Murex Fillex, is designed for fillet welding and other down-hand work. Welds made with this electrode have physical properties meeting the AMERICAN WELDING SOCIETY'S specifications for Grade 10 Filler Metal.

### THE WELDER'S TROUBLE SHOOTER

"The Welder's Trouble Shooter," an 8-page booklet, lists the common troubles met by welders, together with the cause and cure for each. Some of the troubles mentioned are: distortion, welding stresses, cracked welds, undercut, porous welds, brittle joints and corrosion.

Copies of this booklet, B2150-A may be secured from the nearest district office of Westinghouse Electric & Manufacturing Company or from headquarters at East Pittsburgh, Pennsylvania.

## EMPLOYMENT SERVICE BULLETIN

### POSITION VACANT

V-87. Welding Superintendent, who must be thoroughly familiar with the fabricating of large, heavy welded structures. Company manufactures large welded steel power presses and has a Welding Department which employs approximately 80 men. He must have a thorough knowledge of modern welding practice, and must have the ability of handling a good class of men.

### SERVICES AVAILABLE

A-285. First-class welder capable of doing X-ray and all position welding. Willing to go anywhere.

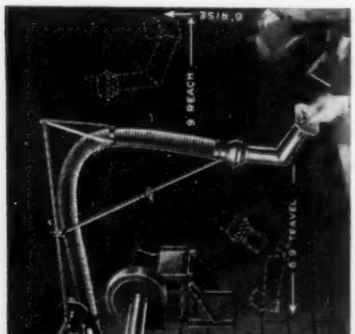
A-286. Arc Welder—15 years experience—oil in field, mine, shipyard, railroad and tank construction. Passed Navy and A. S. M. E. tests—has done considerable Class II work. Several years experience abroad.

# NEW PRODUCTS

**The Society assumes no responsibility for the validity of claims in this Section**

## WELDING FUME COLLECTOR

The Ruemelin Mfg. Company announce a new Fume Collector designed to remove the irritating gases, smoke and heat caused by arc welding. Such modern ventilation by means of local exhaust hoods has proved very practical in service as it collects the fumes at the source of




generation, instead of exhausting the entire shop atmosphere. Such fumes are exhausted outdoors as no filtering unit is known to eliminate dangerous gases.

The Ruemelin Mfg. Company offer their Bulletin 37-B upon request, as well as engineering and installation data on fume collection problems.

## NEW TYPE OF ROOF AND FLOOR CONSTRUCTION

By eliminating shop preparation of materials and by cutting down the time required for a job, Harvey W. Schick, Inc., Chicago, estimates that electric arc welding saves approximately 50 per cent in the construction of its special-type roofs and floors. The Schick method of floor and roof construction involves the

placing of long, shallow pans over the structural steel supporting members, welding these pans together and to the supporting beams, and, finally, filling the pans with concrete. The method results in a stronger and more rigid job, with a saving in cost and time.

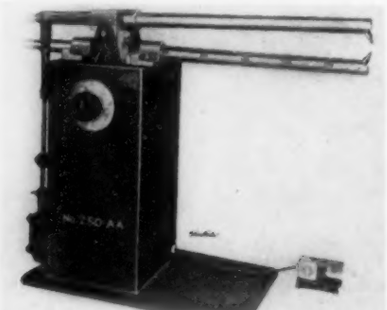
The individual sections, or "pans," are pressed into shape from prime hot-rolled sheets. They are bent uniformly to size, and the variation in the height of the sides, or "ribs," does not exceed $^1/_{32}$ inch. When the pans are laid side by side over the supporting members of a roof or floor, these ribs form "I" beams at their intersections. The electric welding of the sections to the steel framework of the building prevents any rocking or vibration between the floor system and the framework, gives practically a fixed end bearing for the sections, and provides lateral bracing for floor beams or roof purlins. It also makes possible the placing of this type of deck over beams having a different pitch or warped surfaces where the cost of building wood forms for a reinforced concrete slab would be prohibitive.

The sections do not require any intermediate supports during the time the filling is being placed. Bricks have been piled two feet high on 12-foot span sections before the filling was placed, without any noticeable deflection and without damage to the sections.

Previously, the company used a bolted construction or one involving the use of rivets. These methods, however, necessitated the punching of bolt or rivet holes and a more laborious use of various tools both in the shop and in the field. But now, using arc-welding, this company turns out a higher quality job in less time and at the estimated saving of 50 per cent.

## UNIVERSAL SPOT WELDER

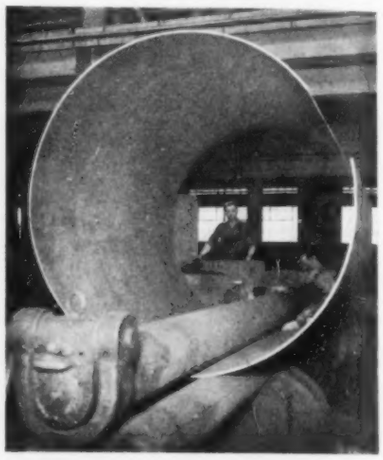
The Eisler Engineering Company of 750 South 13th Street, Newark, New Jersey, have placed on the market a Universal Long Horn Spot Welder for deep sheet metal work. The novel feature of the machine is that both horns, the upper and lower can be lengthened or



shortened to the desired type and size of work. The new feature claims that the horn adjustment makes it possible to weld light and heavy work and deep metal parts. Note the markings on the horn, which represents the kva. ratings—when the horn is placed on the 25 mark it represents 25 kva. when the horn is readjusted to 50 it represents a 50 kva. The Spot Welders are made with many different styles of welding tips, in this case, the water cooling goes through the entire arm.

## A NEW TYPE OF WRINGER

*Just like the wringer on Ma's washing machine. . . .* except that the dainty little piece going through these rollers is a heavy section of sheet steel. It is being rolled



into a cylindrical shape by workers in General Electric's Philadelphia plant and will become a tank body for a large oil circuit breaker.

## NEW ALLOY HAS STEEL'S STRENGTH

### "Z" Nickel Combines Corrosion Resistance of Nickel with the Mechanical Properties of Heat-Treated Steel

Heat treating which has been used so successfully in the production of high-strength alloy steels is now being applied to a nickel alloy which—in addition to the mechanical properties of such steels—has the corrosion resistance of nickel.

While this new material is an alloy, it contains 98% nickel. It represents the result of more than six years of laboratory developments and field study.

Introduced as "Z" Nickel, the alloy has a strength of from $2^1/_2$ to 4 times that of ordinary structural carbon steel. It has been produced with a tensile strength as high as 250,000 psi and hardness values as high as 46 Rockwell C.

## BINOCULAR PRISM MAGNIFIER FOR THE EXAMINATION OF WELDING SEAMS

With the magnifier, the weld is examined for penetration, porosity and cracks. It enables the welding engineer to examine the weld thoroughly at any time and at any stage of production, and to detect defects which he would otherwise never have seen. Bad penetration, porosity and tiny cracks may be detected with ease. Even the hairline cracks which are

invisible to the naked eye, and which may assume such dangerous proportions, can be satisfactorily detected with the instrument. E. Seitz, Inc., 730 Fifth Ave., New York., N. Y.

### NEW HIGH-SPEED AIR CONTROL VALVES

Two new solenoid controlled air valves have been announced by the Ross Operating Valve Company, 6481 Epworth Boulevard, Detroit, Michigan. Both of these units are especially designed for high-speed service such as that required for numerous welding operations. One of these units is for the control of single acting and the other for the control of double acting cylinders.

The manufacturer claims that the utilization of air line pressure for reversing the valve action is an unusual feature; elimination of return springs makes possible the use of smaller solenoids.

### LOW-COST RESISTANCE WELDING PROCESS

General Electric engineers have developed a low-cost resistance welding process of an electronic type to replace expensive soldering operations in the manufacture of such devices as radio sets, watches, small meters, industrial control devices, railway signal equipment and business machines.

A current of several thousand amperes flows in the secondary circuit of the welder for a half-cycle which is precisely timed by an Ignitron tube and its associated control circuit. This control circuit includes a dial for regulating the heat by the phase-shifting method. The amount of heat is accurately determined by the duration of current flow; maximum heat is obtained with a current duration of slightly more than $^{3}/_{120}$ of a second. The welding transformer and its associated equipment are suitably enclosed.

# List of New Members

**August 1 to August 31, 1938**

#### BIRMINGHAM

**Simmons, W. A.** (D), 2109 N. 19th St., Bessemer, Ala.
**Williams, R. L.** (D), Goslin Birmingham Mfg. Co., 3700 Tenth Ave., No. Birmingham, Ala.

#### BOSTON

**Gray, Henry F.** (C), 92 Packard Ave., W. Somerville, Mass.

#### CANADA

**Balzer, Otto** (C), Sherrit Gordon Mines, Sherridon, Manitoba, Canada.
**Gour, Phillipe** (D), Noranda Mine, Noranda, Quebec, Canada.
**Latta, A. L.** (B), D. G. Latta, Ltd., Edmonton, Alberta, Canada.
**Theriault, M.** (D), Noranda Mines, Noranda, Quebec, Canada.

#### CINCINNATI

**Campbell, Howard** (B), Gardner Publications, Inc., 431 Main St., Cincinnati, Ohio.

#### CLEVELAND

**Jennings, Jack** (D), 7714 Lawn Ave., Cleveland, Ohio.
**Noonan, Thos. J.** (B), The East Ohio Gas Co., Foot of E. 62nd St., Cleveland, Ohio.

#### DETROIT

**Schimpke, Albert J.** (C), Murray W. Sales Co., 801 W. Baltimore, Detroit, Mich.

#### HAWAII

**Carpenter, B. P.** (B), Hawaiian Gas Products, Box 2454, Honolulu, T. H.
**Lee, H. T.** (B), Pacific Welding & Mach. Wks., 551 So. St., Honolulu, T. H

#### LOS ANGELES

**Cottrell, W. P.** (C), Cottrell Engrg. Co., 207 Mesnager St., Los Angeles, Calif.

#### NEW YORK

**Cullen, L. J.** (D), 199 Beach Road, Great Kills, S. I., N. Y.
**Freitag, A. J.** (D), J. E. Mergott Co., 316 Jelliff Ave., Newark, N. J.
**Hodges, Charles** (C), Standard Oil Co. of N. J., Bayway Refinery, P. O. Box 16, Elizabeth, N. J.
**Hila, John** (D), 46 Wheeler Ave., Carteret, N. J.

#### NORTHWEST

**Adler, Robert** (C), Adler Steel Products Co., 310 Thorpe Bldg., Minneapolis, Minn.
**Sage, V. L.** (C), National Cylinder Gas Co., 2420 University Ave., St. Paul, Minn.

#### OKLAHOMA CITY

**Simms, Howard N.** (D), Black, Sivalls & Bryson, Inc., P. O. Box 1377, Oklahoma City, Okla.

#### PEORIA

**Isgren, Vernon R.** (B), 4201 Prospect St., Peoria, Ill.

#### PHILADELPHIA

**Feniewicz, Roy** (D), c/o Elec. Welding Co., Torresdale Ave. & Paul St., Frankford, Philadelphia, Pa.

#### ROCHESTER

**Smith, Englert** (C), 517 Erie Blvd., E., Syracuse, N. Y.

#### SAN FRANCISCO

**Mainwaring, N. R.** (B), 425 Kentucky Ave., Berkeley, Calif.

#### SOUTH TEXAS

**Berg, O. E.** (C), The Babcock & Wilcox Tube Co., 1007 Electric Bldg., Houston, Texas.
**Brunt, Roy** (B), Magnolia Airco Prods. Co., P. O. Box 319, Houston, Texas.
**Burns, T. V.** (C), Magnolia Airco Prods. Co., P. O. Box 319, Houston, Texas.
**Hamilton, L. A.** (B), Magnolia Airco Prods. Co., P. O. Box 319, Houston, Texas.
**Meyers, G. A.** (B), Magnolia Airco Prods. Co., P. O. Box 319, Houston, Texas.
**Sugg, L. D.** (B), Magnolia Airco Prods. Co., P. O. Box 319, Houston, Texas.
**Wilkins, E. L.** (B), Magnolia Airco Prods. Co., P. O. Box 319, Houston, Texas.

#### WASHINGTON, D. C.

**Falcover, A. E.** (C), 3511 22nd St., N. Arlington, Va.
**Horn, A. M.** (C), 4 Carvel Rd., Westmoreland Hills, Friendship Sta., Washington, D. C.
**Skinner, O. B.** (C), 4443 Ellicott St., N. W., Washington, D. C.
**Snyder, P. W.** (C), 1870 Wyoming Ave., N. W., Washington, D. C.
**Trexel, C. H.** (C), Bureau of Yards & Docks, Navy Dept., Washington, D. C.

#### WICHITA

**Wilhite, J. B.** (D), 607 S. Hydraulic, Wichita, Kans.

#### YOUNGSTOWN

**Fetz, A. F.** (C), 848 Mahoning Ave., Warren, Ohio.

#### NOT IN SECTIONS

**Cox, Jr., A. T.** (B), 1205—4th Ave., Moline, Ill.
**Ellve, Eric** (C), Casilla 605, Lima, Peru, South America.
**Keatley, Gordon M.** (D), 1319 Quarrier St., Charleston, W. Va.
**Graybill, J. S.** (C), Leola, Pennsylvania.
**Loeb, S. C.** (C), Welding Supply Co., 111 W. Tayler St., Syracuse, N. Y.
**Myers, J. F.** (B), Tennessee Copper Co., London Mill, Copperhill, Tenn.
**Stander, E. R.** (D), 1203 Whites Road, Kalamazoo, Mich.
**Townsend, A. J.** (B), Lima Locomotive Wks., Inc., Lima, Ohio.
**Wishart, Wm.** (B), American Bureau of Shipping, 1412 Hibernia Bank Bldg., New Orleans, La.
**Yetter, G. L.** (C), c/o Bureau of Reclamation, Coulee Dam, Wash.

*It isn't* "JUST A NOTION"

*that*

# McKAY ELECTRODES *work better*

YOU'LL EXPERIENCE IT IN YOUR OWN SHOP

An operator will soon feel that he is getting superior results with McKay Electrodes; but it is the inspection card and the tally sheet that tell the story. Not only faster, quieter progress and less spatter but greater uniformity of sound, perfect looking welds are what McKay Shielded-Arc Electrodes have been demonstrating in the plants of many users now for months. The right rod must be chosen, of course. We shall be glad to help you choose the right McKay Electrode for *your* work and supply samples for test. Ask for folder describing the complete line.

**THE McKAY COMPANY** McKAY BUILDING PITTSBURGH, PA.

THE ENGINEERING FOUNDATION
Welding Research Committee
Sponsored by the American Welding Society
and American Institute of Electrical Engineers

Supplement to the Journal of the American Welding Society, October 1938

# THE CARBON ARC WELDING OF SILICON BRONZE*

By E. S. BUNN, J. R. HUNTER and W. G. SEIDLITZ†

THE increasing use of silicon bronzes in the fabrication of tanks and vessels to meet A. S. M. E. Unfired Pressure Vessel Specifications has been accompanied by increased interest in the carbon arc method of welding these alloys. The interest in this method has been due in part to the lack of bare or coated metallic arc electrodes that approach, both as regards performance and deposited metal quality, similar electrodes of other alloys. While automatic bare rod metallic arc welding is successfully employed in the fabrication of light gage hot water tanks, the intermittent and globular transfer of metal makes for poor control in manual welding unless a relatively large molten pool is maintained to absorb the globules as they are deposited. Such welds are generally coarser grained and not as clean or as dense as those made by the carbon arc and gas methods. While oxyacetylene welding has been until recently the only reliable method for welding the heavier gages, it is relatively expensive and attendant by certain fabrication difficulties. Users of this method have occasional trouble with closed structure welds cracking because of the hot shortness (lack of strength and ductility at elevated temperatures) of these alloys.

Generally the carbon arc method has been the most widely used in both light and medium gage fabrication. There have been various recommended procedures [1,4,5] and techniques, none of which have been generally or uniformly followed. These differed widely in the recommended number of beads, rod sizes, welding currents and arc lengths. While backing was generally recommended as a mechanical support for the molten weld-metal, shops generally balked at this practice because of the difficulty and expense of setting up. The quality of the welds made with the carbon arc method varied over wide limits, and welds in medium and heavier gages were in many cases unreliable in that they were not consistent as regards strength, ductility and freedom from inclusions and porosity. The benefits of peening are known and have been published [2,3,6,8,9] although until recently peening seems to have been little or seldom used except to close up porosity in poor welds.

The present investigation was undertaken for the purpose of developing a procedure for carbon arc welding silicon bronzes to meet A. S. M. E. Par. U60 Specification at a minimum cost. The results obtained indicate that high strength welds are obtainable without the necessity of peening. Previous work conducted by the authors indicated that improvement of welds made with a standard flux could be effected by peening. However, such improvement was accompanied by higher cost as it requires approximately as much as $1^1/_2$ to 2 times as long to peen a weld as to deposit it.

## GENERAL DISCUSSION
### METHOD, ARC LENGTH, NUMBER AND THICKNESS OF BEADS, FLUXES, PEENING

The problem in carbon arc welding has been one of choosing a procedure and technique that would be workable under practical conditions and that would yield the necessary weld quality at a minimum cost.

It should be noted that the carbon arc method has points of similarity to both gas and arc welding, the technique employed being similar to that used with the former method. The carbon arc method has the flexibility of the gas method in that the source of heat is independent of the size and amount of filler metal added. Since, however, with the carbon arc the temperature is more intense and the rate of flow of heat greater than in the case of the gas torch, there are greater possibilities of overheating on the one hand and of cold welding in an effort to prevent overheating on the other hand. Welders in general have failed to recognize the necessity of manipulating both rod and electrode when carbon arc welding and have attempted to mechanize the movement of the electrode. As in the case of gas welding, manipulation of the filler rod is important. The optimum welding speed varies somewhat for each individual welder and the use of recommended amperages without the proper correlation between the rate of welding along the seam and the amperage used can cause, because of the high rate of heat flow, large variations in the quality of the resulting welds.

Sufficient emphasis has in general not been placed on the pattern or path of motion of the carbon electrode in welding. The electrode should be so manipulated as to effect the maximum heating of the edges of the parent metal while at the same time the overheating of the central portion of the weld-metal is avoided. In weaving the electrode back and forth across the weld, crossing of the same point in the centerline should be avoided. This

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centerline of the weld is naturally the hottest section of the weld as is amply illustrated by the tendency of a vertical weld to sag in the center. An experienced welder "whips" the electrode to prevent this condition; in other words, he attempts to concentrate the addition of heat and metal to the weld at the edges of the bead.

In horizontal welds, with the carbon arc, the visible sagging or dripping of the centerline portion may not afford visual evidence of overheating at the center but nevertheless care must be exercised to concentrate the heat and addition of metal at the edges of the weld if proper bonding is to be accomplished and cold welds at these points avoided.

The proper arc length, the nature and solubility of flame gases, the effect of carbon transfer, and the relation between the arc length, current and rod diameter all have to be considered with respect to their mutual relationship. While a short arc ($^3/_{16}$ inch) tends to, with all other conditions equal, promote rapid freezing as a consequence of a possibly smaller molten weld pool, the carbon transferred through the arc often stiffens up the floating slag to the point where easy and rapid blending of weld and parent metals is difficult. Especially is this true when the carbon electrode is weaved rapidly as it is in carbon arc welding and vee walls are frequently approached more closely than intended. A small weld pool, indicative of a smaller area covered by the arc, also necessitates more care in weaving so that areas at the edges of the weld are not left unfused, or slag included there. This is of considerable importance when it is remembered that lineal speeds along the seam vary between 7 and 12 inches per minute.

A long arc tends to keep a larger amount of metal molten because of the greater spread of heat. This same spread results in some preheat and a cleaner molten metal surface in contact with gases which are definitely less reducing in character. Carbon transfer also is less troublesome and less exact weaving is required.

The choice of an arc length governs, to a large degree, the results obtained. The results given in Table 1 indicate a long arc superiority over a short arc in so far as weld-metal quality is concerned.

In the case of unbacked welds, however, a long arc in all beads is impractical. For a given amperage and rod size, the longer the arc the greater the tendency for the filler rod to melt ahead of the point of arc contact and for the weld-metal additions to be globular and intermittent. Cold welding, inclusions and frequent dropping through result while welding in the root of a vee and until sufficient metal has been laid in the vee to provide ample bottom for subsequent beads. Experience indicates an optimum arc length of $1^1/_2$ to 2 times the optimum filler rod diameter for the particular bead.

In the selection of the optimum procedure and technique, it is recognized that in carbon arc welding the human element is involved to a large degree. Working as such, a welder functions through his eyes and what he cannot see he can only surmise. While a weld should be made in as few beads as possible, for economic reasons, additions of filler metal should never be so great as to prevent the welder's observing at all times just when fusion of bead to bead and weld to parent metal has been obtained.

Earlier experiments have indicated that in comparing backed up multi-bead welds with those made with few beads, the former, while freer of inclusions and porosity,

**Table 1**

| | Weld No. 918 | Weld No. 919 |
|---|---|---|
| Arc length, all beads | $^3/_{16}$ in.–$^1/_4$ in. | $^1/_2$ in.–$^5/_8$ in. |
| Beads 1 & 2 Rod diameter | $^1/_4$ in. | $^1/_4$ in. |
| Beads 1 & 2 Amperage | 100 | 100 |
| Bead 3 Rod diameter | $^3/_8$ in. | $^3/_8$ in. |
| Bead 3 Amperage | 200 | 200 |
| Reduced Section Tensile Strength (Average 2 Specimens) | 50,800 | 52,000 |
| Weld-Metal Free-Bend Ductility (Average 2 Specimens) | 36%* | 63% |

*Remarks:* (Both welds copper backed. 90% fused borax, 10% sodium fluoride applied as alcoholic paste.)

* While ultimate failure occurred in the center of the weld for both tensile and bend specimens, on both types of specimens the weld-metal tore partially away from the parent metal.

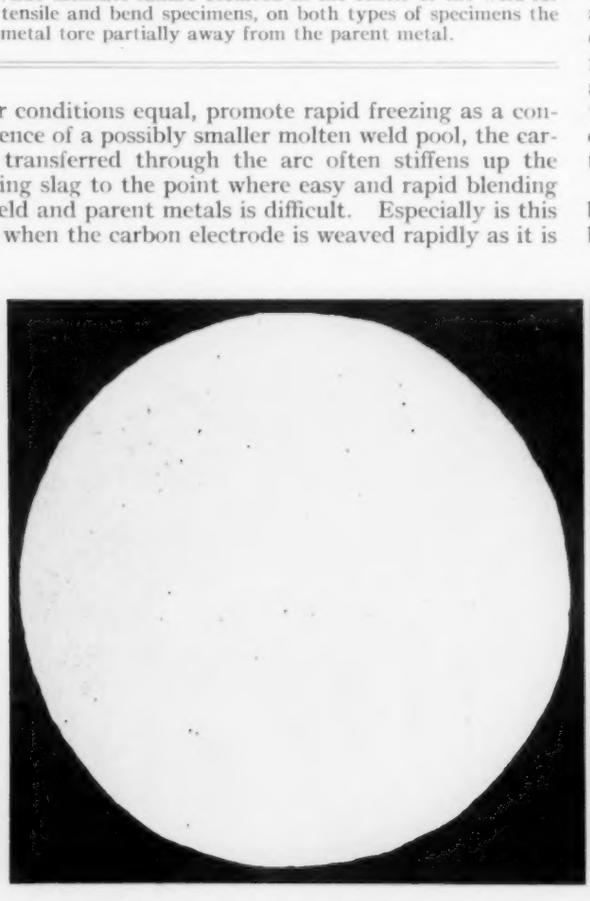

Fig. 1—Unetched—75 X. Specimen F, Weld No. 20 ($^1/_2$-Inch Plate). Tensile Strength Adjacent Specimen 54,600 Psi (Reduced Section)

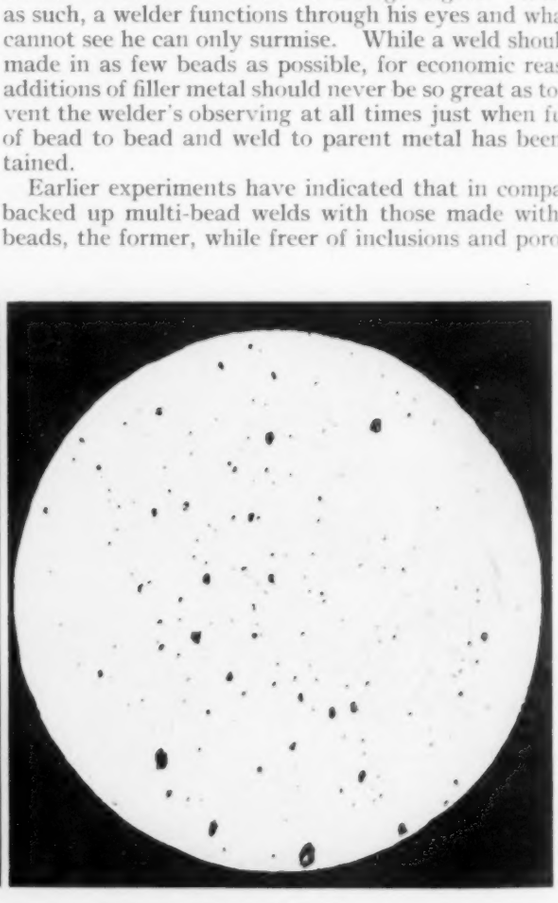

Fig. 2—Unetched—75 X. From Weld in $^3/_8$-Inch Plate. Tensile Strength Adjacent Specimen 49,000 Psi (Reduced Section)

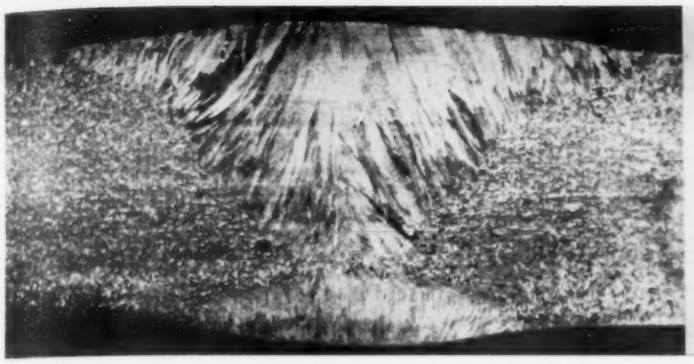

Fig. 3—Chromic Acid Etch—5 X. Specimen F, Weld No. 20 (1/2-Inch Plate, Improved Flux). See Table 3

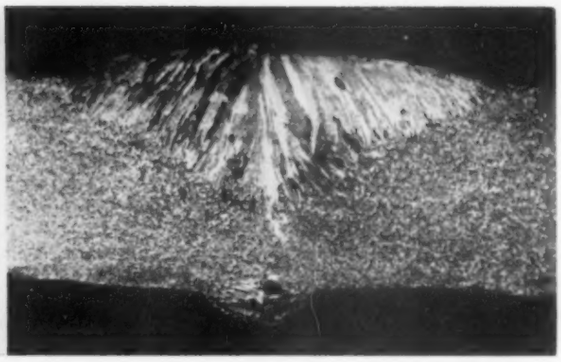

Fig. 4—Chromic Acid Etch—5 X. From Weld in 3/8-Inch Plate, Standard Flux

are generally low in strength (40–50,000 psi) possibly due to the greater number of opportunities to overheat. Results on few-bead welds are often erratic, at times being of low strength, presumably for the same reason, while at other times high strength (45–53,000 psi) welds are marred by too frequent and relatively large slag inclusions. The backing, while it serves to support molten weld-metal, allows of overheating to almost any degree, without such overheating becoming apparent during the welding operation. Any chilling effect the backing might exert is more or less confined to the first or second beads, particularly the former—the one with which it comes in intimate contact. Comparative experiments indicate that 1/8 inch thick bead additions are all that can be handled with any assurance of proper fusion.

Even though general improvement in the quality of the welds was effected when such factors as arc length, number and thickness of beads and path of motion of the electrode were properly correlated, it became apparent that in order to obtain consistency of weld strength desired it would be necessary to give careful consideration to the flux used. The commonly used 90% fused borax, 10% sodium fluoride flux, applied as a thin alcoholic paste to bead and vee wall surfaces, often caused trouble in the deposition of the first two or three beads in a vee because of poor fluidity. The continued application of the arc to float flux (or slag) accumulated at the edges of the weld resulted in sufficient overheating to cause the molten weld-metal to sag or drop through. Literature makes reference to a flux not being so important in carbon arc welding[7] and that no flux is better than an excess.[9] The authors' experience with unfluxed, unbacked welds on which it was necessary to use a comparatively short arc (3/16 inch–1/4 inch) on the first two beads has been that the carbon transfer and oxide formation was particularly aggravating in preventing easy and rapid blending of weld and parent metals. Even in the upper beads of thick-plate welds where a longer arc was feasible because the bead being laid down was better bottomed, sufficient molten scale accumulated to prevent easy blending. Welds so made were generally never as clean, and were usually coarser grained than those on which a flux had been used.

The standard 90% borax, 10% sodium fluoride flux was improved by the addition of other ingredients. The ease with which beads were laid down was noticeably improved, which in return was reflected in the weld-metal density. Following casting shop practice, a scavenger was also added to the flux. A further improvement in density, mechanical properties and consistency of results was noted in welds made with a flux consisting of twenty-five per cent each (by weight) of sodium fluoride, barium carbonate, fused borax and manganese boride.

Figure 1 illustrates the improvement effected in weld-metal density by the use of this improved flux. Figure 2 illustrates the density of a typical weld when standard 90% fused borax and 10% sodium fluoride flux has been used. Photomacrographs (Figs. 3 and 4) of the same specimens show that while the improved flux weld has a coarser grain structure, its mechanical properties are actually improved, presumably due to an improvement in the soundness of the weld.

The values in Table 2 are typical of some of the early welds made with the improved flux (all plate hot rolled—soft):

**Table 2**

| Weld No. | Length of Plate | Plate Thickness | No. Specimens | Reduced Section Tensile Strength, Psi Average | High | Low |
|---|---|---|---|---|---|---|
| 13 | 18 in. | 5/8 in. | 4 | 54,400 | 55,000 | 53,200 |
| 17 | 18 in. | 5/8 in. | 6 | 53,900 | 54,900 | 52,500 |
| 19 | 18 in. | 5/8 in. | 5 | 54,300 | 54,600 | 53,300 |
| 31 | 18 in. | 1/4 in. | 4 | 55,800 | 57,600 | 54,800 |

The above data attests the consistency obtainable. Table 3 illustrates the results of tests on free-bend specimens and on other reduced section and full section tensile specimens.

**Table 3**

Weld No. 20: 1/2-In. Hot-Rolled Plate—Single-Vee Joint
Weld No. 36: 3/4-In. Hot-Rolled Plate—Double-Vee Joint

| | Tensile Strength Psi | Weld-Metal Elongation % | Remarks |
|---|---|---|---|
| Weld No. 20 | | | |
| A (free bend) | | 69 | Bent flat to fracture; dense |
| B (metallographic) | | | |
| C (reduced section) | 54,900 | | Fracture in weld-metal; dense |
| D (full section) | 58,000 | | Fracture in plate |
| E (free bend) | | 70 | Bent flat to fracture; dense |
| F (metallographic) | | | See Fig. 3 |
| G (reduced section) | 54,600 | | Fracture in weld-metal; dense |
| H (full section) | 58,200 | | Fracture in plate |
| Weld No. 36 | | | |
| A (free bend) | | 58 | Bent flat to fracture; dense |
| B (metallographic) | | | See Fig. 6 |
| C (reduced section) | 57,800 | | Fracture in weld-metal |
| D ( " " ) | 56,800 | | Fracture in weld-metal |
| E (free bend) | | 73 | |
| F (metallographic) | | | See Fig. 5 |
| G (reduced section) | 56,700 | | Fracture in weld-metal |
| H ( " " ) | 57,100 | | Fracture in weld-metal |

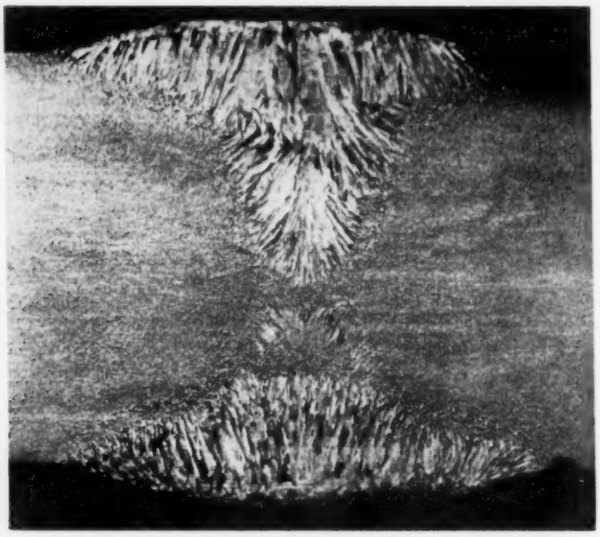

Fig. 5—Chromic Acid Etch—5 X. Specimen F, Weld No. 36

Tests obtained on welds made by an inexperienced operator with no previous background of welding silicon copper alloys are shown in Table 4 as welds "A" and "B." Welds "C" and "D," Table 5, were made by a relatively inexperienced carbon arc welder following the practice outlined in qualification tests. Figures 7 and 8 are X-rays of field welds "C" and "D."

**Table 4**

| Weld | Length of Plate | Plate Thickness | No. Specimens | Reduced Section Tensile Strength Psi Average | High | Low |
|---|---|---|---|---|---|---|
| A | 18 in. | 1/4 in. | 6 | 55,500 | 57,700 | 53,000 |
| B | 18 in. | 1/2 in. | 8 | 54,200 | 55,000 | 53,600 |

**Table 5**

| Weld | Length | Plate Thickness | Reduced Section Tensile Strength Psi 2 specimens | Free-Bend Elongations % in 1/2 in. 4 specimens | | |
|---|---|---|---|---|---|---|
| C | 18 in. | 1/4 in. | 59,600 | 46 | 50 | Bent flat and broke in welds; all welds sound |
| | | | 59,800 | 50 | 42 | |
| D | 18 in. | 1/2 in. | 55,300 | 42 | 46 | |
| | | | 57,000 | 46 | 50 | |

## DETAILED RECOMMENDATIONS FOR THE CARBON ARC WELDING OF SILICON BRONZES

The silicon bronzes are, to state briefly their metallurgical characteristics, high shrinkage alloys of medium thermal and electrical conductivity with a hot short range just below their melting points. Indicative of their low strength when hot is the fact that hot working is not recommended at temperatures above 1475° F. In the liquid state they are comparatively free flowing, but are usually covered with a thin film of silicon oxide which materially increases their surface tension. Such reducing flame gases as carbon monoxide and hydrogen are quite soluble in molten silicon bronzes.

Rapid freezing of the weld-metal is recommended to promote fine grain, to prevent overstressing of weld-metal while it is in a weak temperature range and to generally cut down the exposure time to contaminating flame and ambient air gases.

Silicon bronzes are furnished in both bright dipped and hot rolled finishes as the customer desires. In the latter case it is essential that the black oxide on the parent metal edges and surfaces adjacent to the weld seam be removed. In both cases it is advisable to remove either with emery cloth, a scraper, file or grinder any grease and dirt that may have accumulated in transit or storage. The final cleaning operation should follow any machining, drawing or stamping and should immediately precede welding. Likewise during welding, each bead surface and the adjacent vee walls should be cleaned of oxide, flux and slag before any subsequent beads are laid down. It is good practice to clean the welding rod also.

A flux of the following composition has been found to

Fig. 6(*a*)—Ferric Chloride Etch—75 X. Weld-Metal Specimen G, Weld No. 20

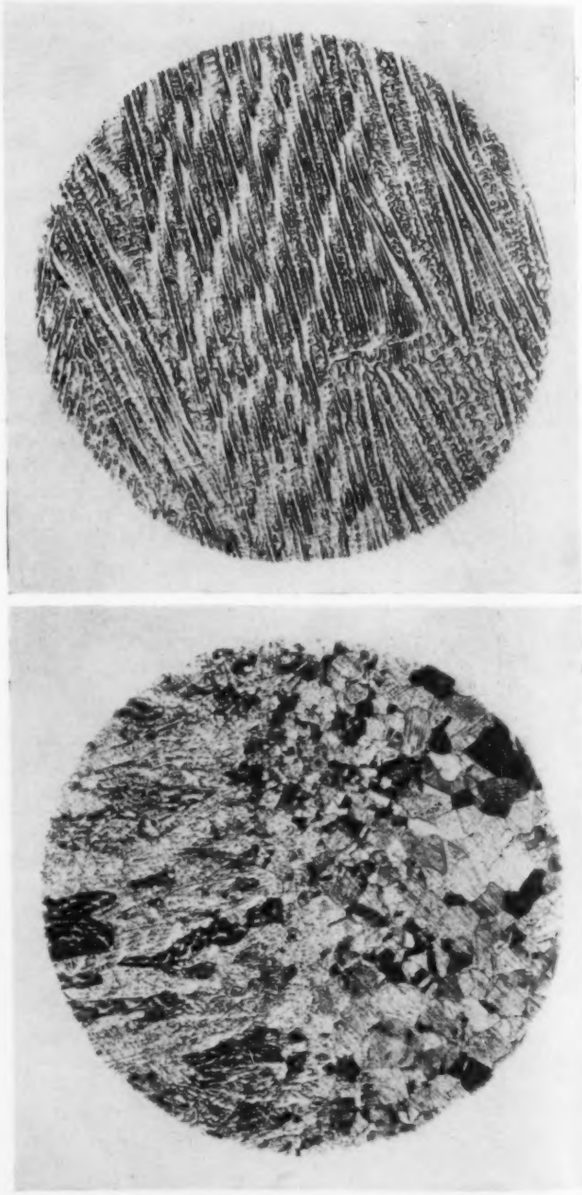

Fig. 6(*b*)—Ferric Chloride Etch—75 X. Juncture, Weld and Parent Metals Specimen B, Weld No. 36

Fig. 7—X-ray Picture. Weld in 1/4-Inch Plate

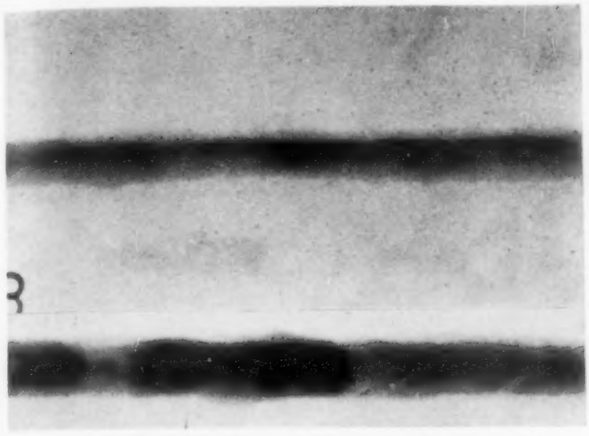

Fig. 8—X-ray Picture. Weld in 1/2-Inch Plate

aid materially in obtaining unbacked and unpeened welds of high strength and ductility:

Twenty-five per cent each by weight fused borax, sodium fluoride, manganese boride and barium carbonate, ground fine and mixed thoroughly. The flux is best applied as a thin paste made up with dry methyl alcohol. The alcohol evaporates readily and leaves the flux adhering to the metal surface. It is important in the preparation of the flux that water-free materials be used and that the flux be kept dry when not in use. Any water present as water of crystallization, or moisture, will volatilize and cause porosity in rapidly freezing weld-metal. The ordinary grocery store variety of borax contains 47% water (by weight) and hence should not be used.

A 60° included angle vee tacked at 6 to 8-inch intervals to maintain an approximate root aperture of 1/8 inch, combined with the bead sequence outlined in Fig. 9 allows of easy thorough penetration, with the minimum of trouble in all beads. For double-vee welding, a modified 60° vee (as shown in Fig. 10) is recommended to eliminate the first bead cracks frequently encountered in unbacked, double-vee welding. The lips of the modified joint are set up in tight contact and no attempt is made to penetrate entirely through the crevices between lip edges. Rather, best practice is to chip from the reverse side to pick up incomplete penetration.

On setting up and in tacking the component parts of a structure together, points to be tacked should, of course, be properly fluxed inasmuch as the tack metal ultimately becomes a part of the finished weld and its soundness is just as important as that of the latter. Because of the rapidity with which the weld-metal freezes, its hot shortness and characteristic high shrinkage, the crater-weld metal is often overstressed in a weak temperature range and may crack unless care is taken to feed the shrink of the crater when welding is discontinued, even momentarily. This is easily accomplished by lengthening the arc slightly and directing it on the end of the filler rod. Very little excess metal is required, the exact amount depending of course on the crater size. First bead crater cracks will often travel as much as an inch back from the point where the arc was broken and so render tack welds useless. In order to prevent dropping through when feeding crater shrink in the first bead, it is often necessary to pull the bead up one vee wall.

Care should be taken in laying the first bead to re-fuse all tack welds and to make them an integral part of the first bead. This is easily accomplished by removing the filler rod or by dragging it over the tack without varying the carbon electrode's speed of progression along the seam, perhaps with but a slight hesitation at both ends of the tack to assure blending at those points. No weaving is necessary to assure proper fusion of the parent metal edges. The arc length can be varied to compensate for variations in the root aperture which are bound to occur. In any bead, when welding is discontinued and then resumed, care should be taken to re-fuse enough of the portion first deposited to insure blending it with the filler metal added as the bead is continued.

The second bead is perhaps the most difficult to deposit in an unbacked weld. Because of its confinement in the lower portion of the vee, and because of aperture variations, it is often questionable whether fusion to both vee walls and the first bead's surface is more easily accomplished with or without weaving. Weaving of this

Fig. 9

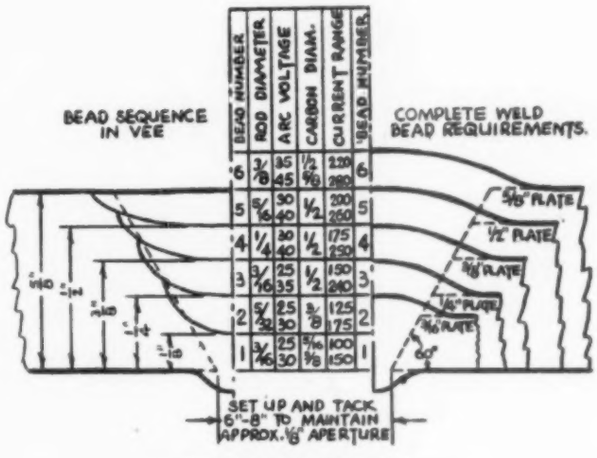


CHART OF RECOMMENDED
CARBON ARC WELDING PROCEDURE
FOR
SILICON BRONZES
SINGLE VEE WELDS 3/16"-5/8" PLATE.

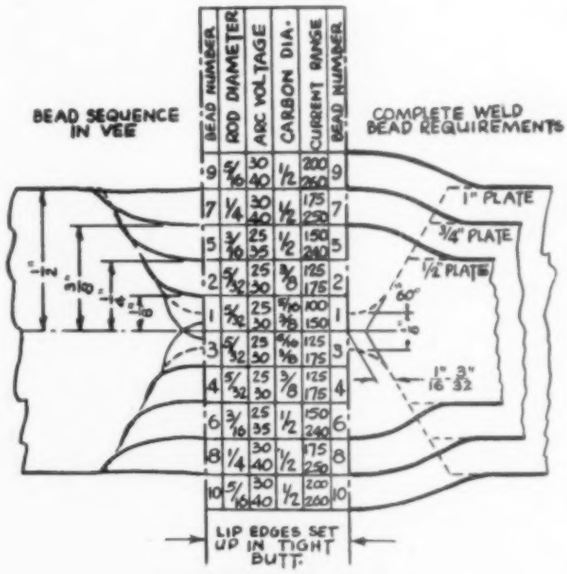


CHART OF RECOMMENDED
CARBON ARC WELDING PROCEDURE
FOR
SILICON BRONZES
DOUBLE VEE WELDS 1/2"-1" PLATE.

Fig. 10

bead must necessarily be restricted and hence be more rapid because of vee wall confinement. A slightly longer arc with perhaps a slightly higher current may often be desirable.

On semicircular weaving for subsequent beads the carbon electrode should be "whipped" across the center of the weld to prevent overheating in that region. The arc should be somewhat concentrated at the edges of the bead, the naturally coldest points in a weld section. Flux, oxide and slag accumulations which may tend to ball up at these points should be particularly watched and floated off. Overheating at any point is, however, to be avoided. Continued application of the arc, once fusion and blending of weld and parent metals have taken place, is nothing more than overheating and may result in a variety of weld-metal defects. The wetting of the previous bead's surface and the parent metal edges by the weld-metal is an indication that bonding has been obtained. If the flowing of the weld-metal bears any resemblance to solder flowing over a dirty or cold surface, it is an indication of insufficient preheat in advance of the molten weld-metal. Inclusions or cold welding may result.

The proper amperage to be used depends somewhat on the individual welder's experience and capabilities. Results indicate that the current may be varied over a fairly wide range as indicated in Figs. 9 and 10, providing that within practical limits the heat input per inch of weld (or bead) is constant.

The filler rod sizes in Figs. 9 and 10 have been chosen so that an inch of filler rod will furnish sufficient weld-metal for an inch of seam. The rod may be weaved where possible to allow contacting of the arc directly on all portions of surfaces to be fused and to allow maximum visibility.

Carbon electrode diameters for given currents should be consistent with manufacturers' recommendations. A pencil point taper with a $^1/_{16}$-inch to $^1/_8$-inch diameter point should be maintained for maximum control over the arc. The proper size electrode will burn evenly to maintain such a taper. Too large a carbon for a particular amperage range "dulls" quickly on burning. Overheating an electrode not only shortens its life, but results in welder discomfort which may be reflected in the weld-metal quality.

As in all welding, any visible inclusions, porosity or cracks should be completely removed and rewelded. The same procedure followed in the original welding should be observed. Any attempt to re-fuse a section of a weld to remove a crack or porosity, or any attempt to fill a chipped-out section in one bead where originally a number were required, may result in cracking.

The procedure outlined herein applies particularly to thicknesses of $^3/_{16}$ inch and over, that is, those gages readily weldable without backing. Backing is recommended for lighter gages, all of which are weldable in one bead. Parent metal edges must be efficiently clamped to backing if the latter is to be of any value The general recommendations regarding cleanliness, fluxing, overheating and feeding of crater shrinkage are again applicable. Crater shrinkage or local overheating may cause, in addition to longitudinal weld cracks, cross-bead cracks that extend into the parent metal. The latter are the more difficult to repair.

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# WELDABILITY OF MEDIUM Carbon Steel*

By R. W. EMERSON†

## INTRODUCTION

MANY variables arise in the commercial arc welding of steel. Due to this fact it becomes difficult to ascertain which variable or group of variables are responsible for the variations in physical and metallurgical properties which are sometimes obtained in welds. Steels with carbon contents ranging from 0.30 to 0.50 per cent undergo marked metallurgical changes as a result of welding, consequently they are the type under consideration in this investigation.

The main difficulty when welding steel above 0.30 per cent carbon is the formation of hard constituents in the heat-affected zone of the base metal directly adjacent to the weld deposit. This difficulty is further amplified when welding heavy sections due to the more rapid removal of the heat from the welded area by metallic conduction of the steel.

It was the purpose of this investigation to study the heat-affected zone of the weld in preference to the weld deposit, consequently the carbon content of the base metal was varied to such an extent that extreme variations were obtained in the hardness of the heat-affected zone. Also, since extreme conditions were desired, the test pieces used were sufficiently large to obtain rapid cooling in the weld and heat-affected area.

## ANALOGY OF WELDING TO HEAT TREATMENT

Fundamentally there are three variables which determine the physical and metallurgical properties of the heat-affected zone of a weld. These variables are as follows:

1. The composition of the base metal.
2. The total heat absorbed by the base metal in welding including the rate at which the heat is absorbed.
3. The rate of heat removal from the base metal (heat-affected zone) which, of course, is governed primarily by the metallic conductivity of the base metal.

This is exactly analogous to the hardening of steels by heat treatment. The hardness obtained in this case is also a function of the base metal composition, the total heat absorbed by the metal (assuming that the temperature is above the $A_3$ range of the steel), and the rate at which the heat is removed. It should be kept in mind that it is primarily this third factor which governs the resultant structure of the steel, whether it be in welding or in heat treatment. In the case of the heat treatment of steel, heat transfer or the rate of heat extraction is controlled by the liquid medium into which the material is being quenched. Carrying this analogy a step further, preheating the work before welding is done to decrease the temperature gradient between the base metal and the weld thus cutting down the rate at which the heat is removed from the piece. Similarly in ordinary heat treating operations, quenching into a liquid medium such as water, which is at a temperature of 80° C. would also cut down the rate of heat removal from the piece to the quenching bath and produce a softer steel than if quenched into water at 25° C.

## FACTORS TO BE CONSIDERED IN WELDING

The total heat absorbed in welding, including the rate at which it is absorbed, is a function of the welding current and welding speed. The effect of welding speed has been pointed out by other investigators and shown to have considerable effect on the resultant structure and hardness of the heat-affected area.[1,2] It is believed that the heat input does not directly affect the hardness and structure of the weld zone but does affect it indirectly by influencing the cooling rate of the heat-affected area. The rate of heat removal from a welded part is a function of the size and shape of the part being welded and also the temperature of the part prior to welding. Size and shape of the base metal is of considerable importance and too often is not given proper consideration. In W. L. Warner's investigation on the heat effect produced in the welding of structural alloy steels it is mentioned that "determinations of heat effect on cross sections of multiple layer welds give valuable and interesting data, but the result obtained shows the final effect due to the multiple layer. A heat effect test of this nature does not usually show the maximum hardening effect on the base metal, which occurs when the first layer is deposited on the cold plate and it is at this point in the making of a weld that cracks may start due to the heat effect on the base metal. The heat of subsequent layers if applied within a reasonable time, will greatly reduce the heat effect of the first layer applied. Hence, the results obtained from a hardness survey on the cross section of the finished weld does not indicate how dangerous or how critical may have been the situation when the first layer was applied." These comments, although correct, tend to exaggerate the importance of data taken on single pass welds.

In some instances it is desired to know more than the value of maximum hardness which will be obtained. Should it be desired to weld steels which give rather high maximum hardness it is quite often necessary to work out a procedure which will give the desired hardness and microstructure when the weld is completed. This will necessarily involve the use of multiple pass welding or preheating and possibly both. If preheating is not used

* Paper to be presented at Annual Meeting, A. W. S., Detroit, Mich., Oct. 16 to 21, 1938. Contribution to Industrial Research Division of Welding Research Committee.

† Chem. & Met. Division, Research Laboratories, Westinghouse Electric & Manufacturing Co., E. Pittsburgh, Pa.

[1] Warner, W. L., Arc Welding of Structural Alloy Steels, AMERICAN WELDING SOCIETY JOURNAL, October 1936.

[2] Theisinger, W. G., Heat Effect in Welding, *Iron Age*, Oct. 15, Dec. 17, 1936 and Feb. 25, March 4, 1937.

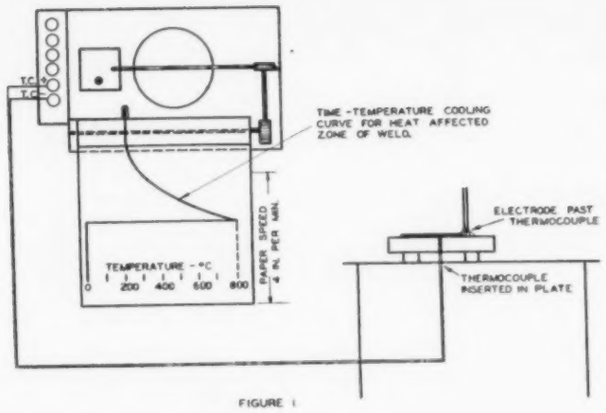

TIME - TEMPERATURE COOLING CURVE FOR HEAT AFFECTED ZONE OF WELD
ELECTRODE PAST THERMOCOUPLE
THERMOCOUPLE INSERTED IN PLATE
TEMPERATURE - °C
0 200 400 600 800
PAPER SPEED 4 IN. PER MIN.

FIGURE 1

the probability of a crack forming in the first bead is high. If preheating is used this probability is greatly reduced.

It is felt, however, that if the time-temperature relation for the cooling of the heat-affected zone is known for any given set of conditions under which welding is to take place, the probability of formation of cracks during welding may be still further reduced because this information will be a direct indication as to the structure which will be formed as a result of each pass. This information will also indicate whether or not preheating is necessary. The importance of the sub-critical time-temperature cooling curve lies in the fact that the rate at which the heat-affected area cools, governs primarily, if not entirely, the resultant structure and hardness of this zone.

## EFFECT OF PLATE THICKNESS

As previously mentioned, the effect of the size and shape of the piece being welded will definitely affect the rate at which the heat-affected area will cool. A diagrammatic sketch of the set-up used to obtain time-temperature cooling curves in heat-affected zones is shown in Fig. 1. This consisted of a temperature recorder having a paper speed of four inches per minute. A hole was drilled in the plates to be tested, sufficiently large to insert a thermocouple from the bottom of the plate to within approximately $^1/_{32}$ inch of the top of the plate. A weld was then made across the plate and as the arc crossed the top of the thermocouple an almost instantaneous rise in temperature was obtained followed by a rather sharp drop in temperature as the arc traveled beyond the location of the thermocouple. The effect of plate thickness on the cooling rate of single-pass welds are shown in Figs. 2 and 3. The results shown in Fig. 2 were obtained with a $^5/_{32}$-inch coated electrode, a welding current of 125 amperes, and a welding speed of approximately ten inches per minute, while those in Fig. 3 were obtained using a $^1/_4$-inch coated electrode, 225 amperes, and a welding speed of approximately 10 inches per minute. The results shown in Figs. 2 and 3 seem logical, that is, increasing the plate thickness (keeping other variables constant) results in a steeper temperature gradient, and a lower but quicker flattening out of the time-temperature curve. The significance of the above statement is more profound than it would at first seem.

It is well known that the time required for sub-critical transformation of austenite depends upon the temperature of transformation.[3] Figure 4 shows the time-temperature curve for the sub-critical transformation of austenite in a 0.50 per cent carbon steel.[3] It can be seen that the austenite if not cooled rapidly, will transform at a temperature of 500–650° C. with the formation of fine pearlite (nodular troostite). In order to obtain complete transformation in this temperature range, a cooling rate of 10–15 degrees per second should not be exceeded and preferably this rate should be less. If, however, the austenite is cooled sufficiently rapidly, it will not transform at 500–650° C. but remain as austenite down to a temperature as low as 125–175° C. before transformation would take place. At this temperature a fully martensitic microstructure will result and the hardness will be in the range of 550–700 Vickers.

Referring to Fig. 2, it will be noted that the cooling rate for the $^1/_2$- and 1-inch plate is very rapid at the high temperatures and thus the austenite would no doubt go through the range of 500–650° C. practically untransformed, with the formation of martensite at a temperature of 125–175° C. and at a time varying from 20 to 60 seconds from the time cooling began. Since martensite is definitely undersirable in welded construction, a single pass weld on a $^1/_2$- or 1-inch plate under the conditions of welding current and speed given, should not be used. In considering the $^1/_4$- and $^3/_8$-inch plates, however, it can be seen that these also have a high cooling rate in the temperature range of 500–650° C. and no doubt would go through the above temperature range only partly transformed with the remainder of the austenite transforming to martensite at a temperature of 125–175° C. It may be observed, however, that this temperature is not reached until a period of 3–5 minutes has elapsed, as contrasted to a period of 20–60 seconds after the beginning of cooling as in the case of the $^1/_2$-inch and 1-inch plates. In a period of 3–5 minutes ample time is allowed for the welder to remove the slag from the first pass and start on the second pass before the temperature has dropped to the

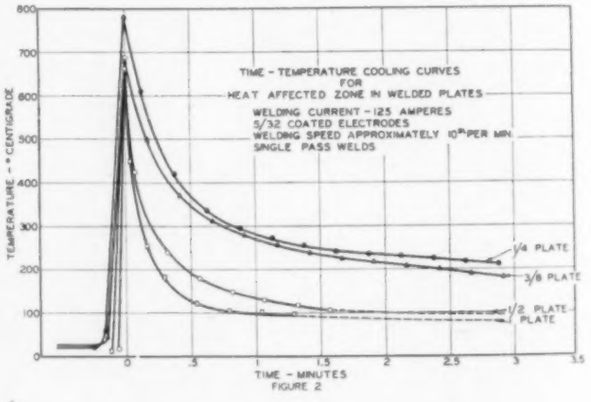

TIME - TEMPERATURE COOLING CURVES FOR HEAT AFFECTED ZONE IN WELDED PLATES
WELDING CURRENT - 125 AMPERES
5/32 COATED ELECTRODES
WELDING SPEED APPROXIMATELY 10" PER MIN.
SINGLE PASS WELDS
TEMPERATURE - ° CENTIGRADE
TIME - MINUTES
1/4 PLATE
3/8 PLATE
1/2 PLATE
1 PLATE

FIGURE 2

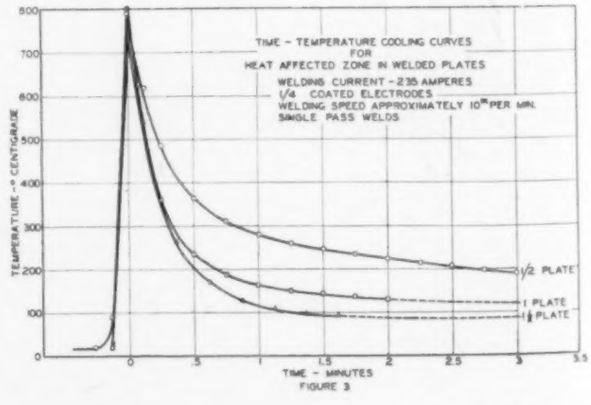

TIME - TEMPERATURE COOLING CURVES FOR HEAT AFFECTED ZONE IN WELDED PLATES
WELDING CURRENT - 235 AMPERES
1/4 COATED ELECTRODES
WELDING SPEED APPROXIMATELY 10" PER MIN.
SINGLE PASS WELDS
TEMPERATURE - ° CENTIGRADE
TIME - MINUTES
1/2 PLATE
1 PLATE
1½ PLATE

FIGURE 3

[3] Davenport, E. S., and Bain, E. C. Transformation of Austenite at Constant Sub-Critical Temperatures, A. I. M. E., 1930.

point at which martensite formation occurs. This, of course, assumes that an average pass would not exceed 12–18 inches in length.

## MULTIPLE-PASS WELDING

As soon as the second pass is started, the bead and heat-affected area (at the point of welding) is reheated to the austenitic stage. At the start of the second pass, however, the plate is effectively preheated from the heat which was put in to the plate at the time the first pass was made. The effect of multiple pass welding on the cooling rate of the heat-affected zone is shown in Fig. 5. From this figure it can be observed that the temperature has dropped from 800° C. (in the heat-affected zone) to a temperature of 130° C. in a period of 2 minutes. At the end of two minutes, however, the slag had been removed and a second pass started. The temperature of the plate is shown as 130° C. at the beginning of the second pass and as the second bead was made the temperature again rose rapidly but this time the temperature drop was slowed up considerably. This of course was due to the fact that the plate was partially heated from the first pass and as a result the temperature gradient between the plate and weld zone was much less than when making the first pass. The temperature of the heat-affected zone two minutes after the second pass was made was 230° C. This would mean that the welder would probably have a period of 4–5 minutes in which to remove the slag, should he need it, before the temperature would lower to the critical temperature range of 175–125° C. Following the second pass by a third, the temperature

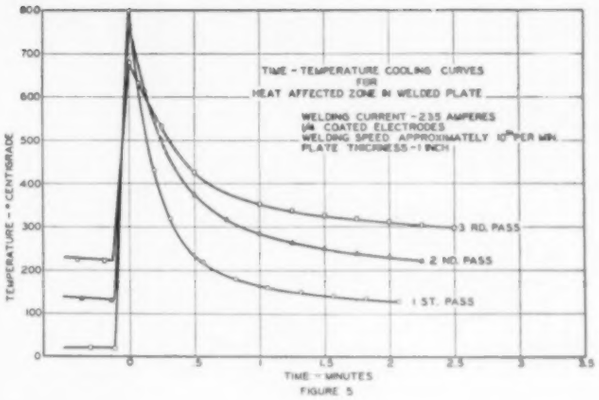


FIGURE 5

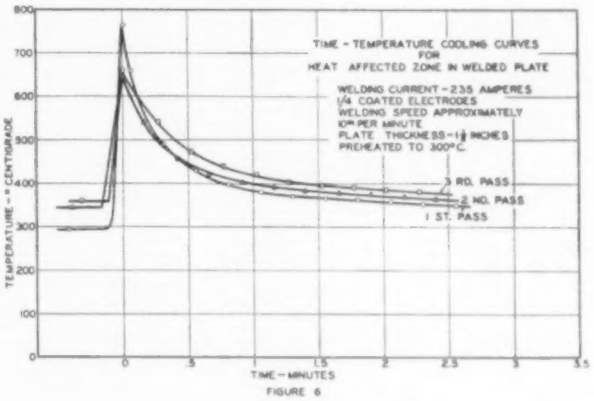


FIGURE 6

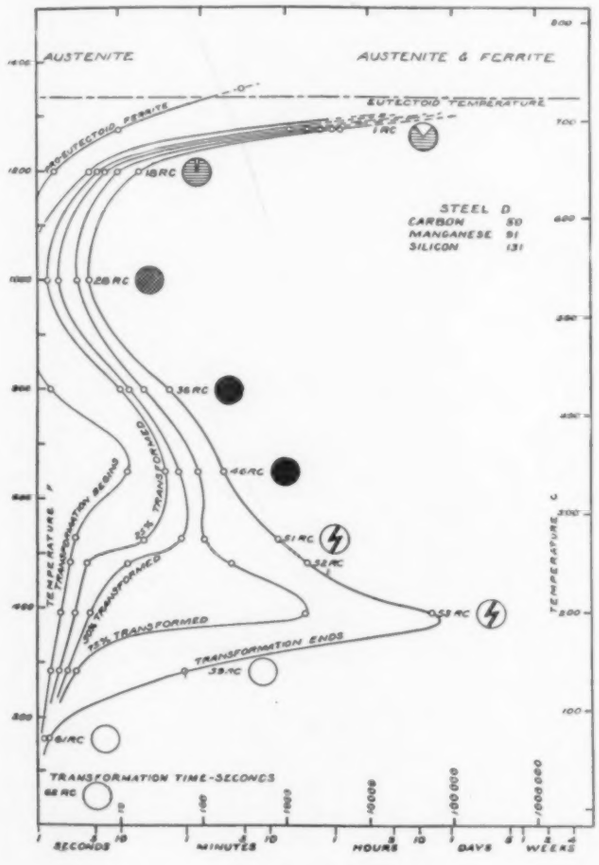


Fig. 4

of the weld zone was again raised into the range above 700° C. and this time the cooling rate of the heat-affected area was much slower than it was with either of the first two passes. The cooling rate for the third pass leveled out at a temperature of approximately 300° C., 70° C. higher than that of the second pass. A point which must not be overlooked is whether or not the time-temperature curve from the last pass is sufficiently flat so that complete transformation will be obtained at 500–650° C. The cooling curve of the third pass shown in Fig. 5 indicates a satisfactory transformation temperature. If it is assumed for example that welding is done on a $1^1/_2$-inch or 2-inch plate it would probably be necessary to use a minimum of 4 or 5 passes so that the time-temperature curve for the final pass would be relatively flat, and thereby insure that all traces of martensite were removed. If the weld required less than the number of passes suggested, preheating could be resorted to, in fact with a $1^1/_2$-inch or 2-inch plate it would be necessary to preheat to 50–100° C. in order to maintain a temperature of 125–175° C. after depositing the first pass. If, for example, five passes were required to obtain the desired structure in the weld zone but three passes were sufficient to obtain mechanical strength, then it would be necessary to preheat the work to a temperature which would be equivalent to the plate temperature following a double-pass weld. It must be kept in mind that the time-temperature curve which results from the final pass is the determining factor in the microstructure and hardness obtained.

## EFFECT OF PREHEATING

Preheating serves the same purpose as multiple-pass welding from the viewpoint of obtaining a satisfactory

**Table 1—Chemical Analysis and Grain Size of Steel Investigated**

| Heat No. | C | Mn | P | S | Si | Grain Size | Remarks |
|---|---|---|---|---|---|---|---|
| 74,218 | 0.49<br>0.46 | 0.93<br>0.92 | 0.018 | 0.032 | 0.20 | 4 to 7 | 3-inch round machined from 3 1/2-inch rolled round. No porosity. |
| 123,467 | 0.43<br>0.42 | 0.68<br>0.66 | 0.018 | 0.032 | 0.22 | 4 to 7 | 3-inch round machined from 4-in. x 4-in. billet. No porosity. |
| 95,115 | 0.40<br>0.39 | 0.78<br>0.78 | 0.018 | 0.026 | 0.15 | 5 to 8 | 3-inch round machined from 3 1/2-inch rolled round. No porosity. |
| 122,555 | 0.33<br>0.30 | 0.71<br>0.72 | 0.019 | 0.042 | 0.23 | 4 to 7 | 3-inch round machined from 5 in. x 5 in. billet. No porosity in billet. |
| 118,261 | 0.32<br>0.29 | 0.67<br>0.62 | 0.016 | 0.032 | 0.14 | 6 to 8 | 3 1/2 - inch forged round. Small pin holes and scattered porosity. |

microstructure and hardness. The function is to decrease the temperature gradient from the weld to the base metal, therefore allowing sufficient time, if possible, for the steel in the heat-affected zone to transform to its sub-critical constituents while still at a relatively high temperature (500–650° C.). If this range of temperature can be held for a sufficient length of time (5–20 seconds) the decomposition products of the austenite will be, as was previously mentioned, of the nature of pearlite. The pearlite may be either fine or coarse depending upon the carbon content of the base metal and the rate at which the heat-affected zone cooled. In cases where the plate thickness is not too great and considerable heat can be put into the plate, multiple pass welding can be used successfully. When a heavy section is welded, however, it is often necessary to preheat the work and in addition to this use multiple passes in an effort to slow down the rate of heat removal from the heat-affected zone so that this area will take a maximum possible time to cool while traversing the range of 500–650° C. The effect on the time-temperature relations, of the heat-affected zone of a three pass welded 1 1/2-inch plate, preheated to 300° C., is shown in Fig. 6. The slopes of these curves are sufficiently flat to indicate complete transformation at the higher temperature range (500–650° C.) with a resultant structure which should be entirely satisfactory.

## TEST PROCEDURE

The chemical analysis and grain size of the steels used in this investigation are given in Table 1.

The test-pieces used for hardness surveys and microstructure examinations were made on specimens 10 inches long by 3 inches diameter. Eight series of beads were run parallel to the length of the rounds. All beads were deposited manually; this resulted in slight variations in welding speed. All tests were at a welding speed ranging from 8 to 12 inches per minute. All beads were run in the same direction on each round and a 3/4-inch slice was then cut from the round at a distance of six inches from the end in which the welding was begun. Each of the fourteen rounds contained the following bead.

Single pass—3/16-inch bare wire electrode
Single pass—5/32-inch flux coated down-hand electrode
Single pass—1/4-inch flux coated fillet position electrode
Single pass—1/4-inch flux coated down-hand electrode
Double pass—3/16-inch bare wire electrode
Double pass—1/4-inch flux coated down-hand electrode
Triple pass—3/16-inch bare wire electrode
Triple pass—1/4-inch flux coated down-hand electrode

One test piece from each of the five steels listed in Table 1 was welded without preheating, a second set was welded with 150° C. preheat and the third set was welded with 300° C. preheat.[4]

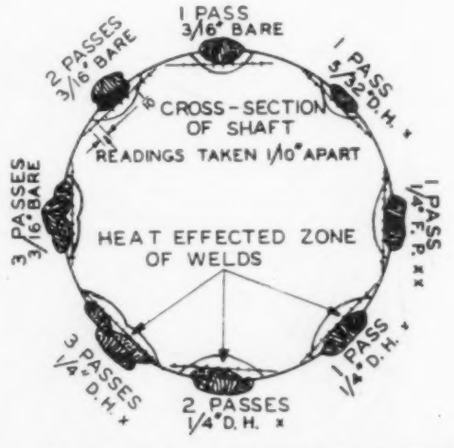
After cutting, polishing and lightly etching the slices, hardness readings were taken in a straight line across the heat-affected zone directly adjacent to the weld-metal as is shown in Fig 7. With those tests which were not preheated, after each bead or group of beads was welded the test-piece was allowed to cool to room temperature before depositing the following bead or group of beads. In the case of the test-pieces which were preheated, after each bead the test-pieces were allowed to cool slightly below the preheating temperature and then allowed to come back to temperature with the furnace. The welding data obtained in these tests are given in Table 2.

## DISCUSSION OF HARDNESS RESULTS

The hardness results were plotted to show the variation in hardness as a function of the carbon content of the steel. The other variables contributing to the hardness were held as constant as possible. A discrepancy which seemed to be prevalent throughout was the hardness re-

[4] Heat 74,218, 150† C. preheat—No sample.

METHODS OF DETERMINING HARDNESS IN HEAT EFFECTED ZONE


1 PASS 3/16" BARE
2 PASSES 3/16" BARE
1 PASS 5/32" D.H. *
CROSS-SECTION OF SHAFT
READINGS TAKEN 1/10" APART
3 PASSES 3/16" BARE
HEAT EFFECTED ZONE OF WELDS
1 PASS 1/4" F.P. **
1 PASS 1/4" D.H. *
3 PASSES 1/4" D.H. *
2 PASSES 1/4" D.H. *

72 VICKERS HARDNESS READINGS TAKEN ACROSS EIGHT HEAT-EFFECTED ZONES

* ELECTRODE FOR DOWN HAND WELDING
** ELECTRODE FOR FILLET POSITION WELDING

FIGURE 7

**Table 2—Current and Voltage Data**

| Heat No. | *1 †I. | E. | 2 I. | E. | 3 I. | E. | 4 I. | E. | 5 I. | E. | 6 I. | E. | 7 I. | E. | 8 I. | E. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **No Preheat** | | | | | | | | | | | | | | | | |
| 74218 | 190 | 15 | 130 | 35 | 300 | 25 | 250 | 36 | 185 | 15 | 250 | 35 | 190 | 15 | 250 | 35 |
| 123467 | ‡ | | | | | | | | | | | | | | | |
| 95115 | 190 | 15 | 130 | 35 | 300 | 25 | 250 | 36 | 185 | 15 | 250 | 35 | 190 | 15 | 250 | 35 |
| 122555 | ‡ | | | | | | | | | | | | | | | |
| 118261 | 190 | 18 | 125 | 36 | 285 | 32 | 245 | 39 | 185 | 18 | 250 | 40 | 185 | 21 | 250 | 38 |
| **Preheat 150° C.** | | | | | | | | | | | | | | | | |
| 123467 | 190 | 18 | 130 | 35 | 280 | 31 | 280 | 38 | 185 | 17 | 280 | 37 | 195 | 17 | 255 | 38 |
| 95115 | 175 | 20 | 120 | 36 | 280 | 31 | 260 | 40 | 185 | 17 | 280 | 38 | 195 | 17 | 250 | 38 |
| 122555 | 190 | 19 | 140 | 33 | 285 | 30 | 250 | 37 | 185 | 17 | 295 | 37 | 195 | 17 | 250 | 39 |
| 118261 | 185 | 19 | 120 | 36 | 275 | 31 | 280 | 35 | 185 | 17 | 290 | 37 | 195 | 17 | 250 | 39 |
| **Preheat 300° C.** | | | | | | | | | | | | | | | | |
| 74218 | ‡ | | | | | | | | | | | | | | | |
| 123467 | 190 | 17 | 135 | 36 | 285 | 24 | 230 | 37 | 190 | 17 | 255 | 36 | 195 | 17 | 250 | 37 |
| 95115 | ‡ | | | | | | | | | | | | | | | |
| 122555 | ‡ | | | | | | | | | | | | | | | |
| 118261 | 185 | 18 | 140 | 35 | 280 | 26 | 250 | 35 | 195 | 19 | 250 | 37 | 195 | 17 | 250 | 36 |

* 1 Single pass—$^3/_{16}$-inch bare wire electrode
2 Single pass—$^5/_{32}$-inch flux coated down-hand electrode
3 Single pass—$^1/_4$-inch flux coated fillet position electrode
4 Single pass—$^1/_4$-inch flux coated down-hand electrode
5 Double pass—$^3/_{16}$-inch bare wire electrode
6 Double pass—$^1/_4$-inch flux coated down-hand electrode
7 Triple pass—$^3/_{16}$-inch bare wire electrode
8 Triple pass—$^1/_4$-inch flux coated down-hand electrode

† I Amperes. E. Volts.
‡ No values taken.

sults obtained on the 0.39 and 0.42 per cent carbon steels. The fact that the steel lower in carbon was higher in manganese would partially offset this difference observed, but certainly not completely explain it. In addition, the

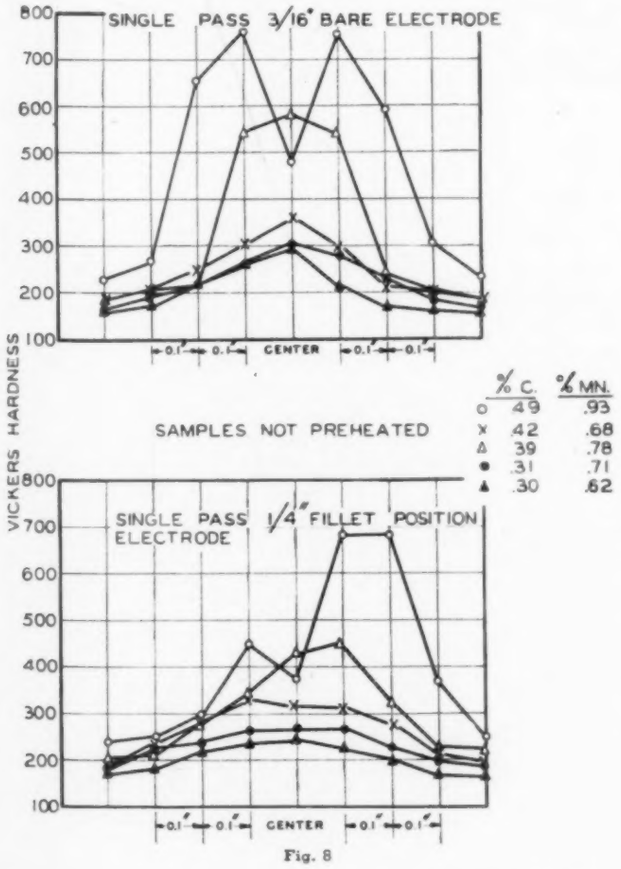



Fig. 8

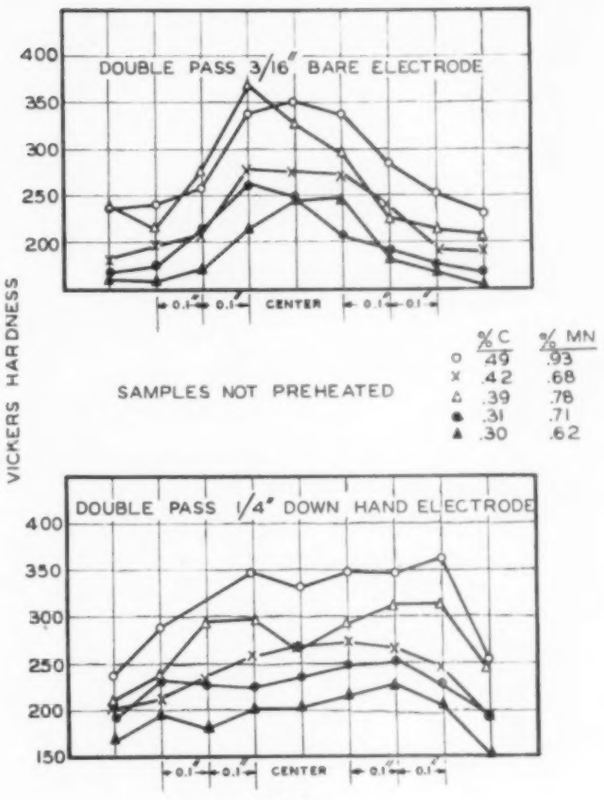



Fig. 9

steel having the higher carbon content appeared to have a slightly larger grain size (lower coarsening temperature) than did the 0.39 per cent carbon steel. The most probable explanation for this variation in hardness would be on the basis of the inherent transformation rates of the two steels.

It is a well-established fact that increased carbon content is conducive to increased hardness. The amount of heat put into the base metal and the rate at which the heat is extracted are factors which are also important in considering hardness. These factors were studied in terms of various sizes of electrodes, various number of passes, and preheating. The results of the hardness tests made are plotted in Figs 8 to 12.

It was noticed from Fig. 8 that the additional heat used in a $^1/_4$-inch coated electrode as compared with the $^3/_{16}$-inch bare electrode had considerable effect on the total area of the heat-affected zone which was hardened. The last statement refers to those steels which were in the critical range of carbon content for welding. (Greater than 0.30 per cent.) It was noticed that for the steels of lower carbon content (0.30 per cent carbon) the single-pass $^1/_4$-inch coated electrode did not lower the hardness to any appreciable extent below that produced when welded with $^3/_{16}$-inch bare electrode.

From Fig. 9 it was evident that a second bead deposited immediately following the first was extremely effective. Here again reference is made to the steels which have critical carbon contents for welding. In contrasting Figs. 8 and 9, the hardness was dropped from 580–760 to 360 Vickers when $^3/_{16}$-inch bare electrodes were used and from 450–680 to 310–360 when using $^1/_4$-inch coated electrodes. The effect of the double pass was not pronounced on the hardness of the lower carbon steel.

In contrasting Figs. 8 and 10, preheating the work to 300° C. lowered the maximum hardness of the $^3/_{16}$-inch

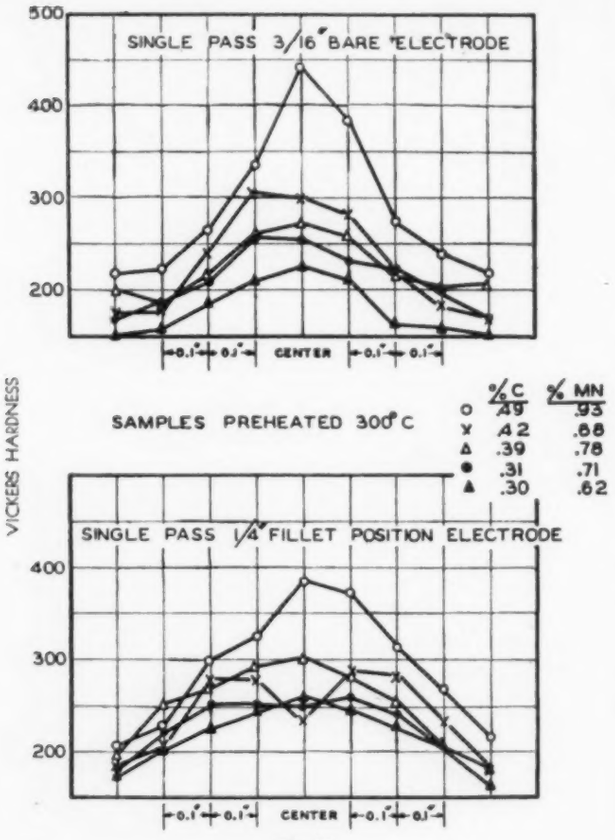



Fig. 10

bare wire weld approximately 300 points Vickers. The hardness of the welds made with the 1/4-inch coated electrodes was also lowered approximately 300 points Vickers.

A contrast of Figs. 9 and 10 indicated that a double-pass weld was just as effective, if not more so, than a single-pass weld and a 300° C. preheat. This result seems questionable, however, in view of the results obtained from the cooling curves. In order for this result to be true it would be necessary that the first pass of the double-pass weld would have to heat the test-piece to a higher temperature than 300° C. This difference may have been due to variations in heat input during welding.

From Figs. 9 and 12 it was noticed that the effect of a third pass immediately following the first two passes dropped the hardness from 350 to 300 Vickers. Contrasting Figs. 11 and 12, three passes without preheating gave approximately the same results as a two-pass weld preheated to 300° C. When the base metal was preheated to 300° C. and a triple-pass weld was used in addition, the hardness was reduced to a figure slightly below 300 Vickers.

Results from these hardness tests indicate that steels in the range of 0.35 to 0.50 per cent carbon can be satisfactorily welded if sufficient heat is put into the weld and parent metal. This would mean that the steel to be welded should be welded under the following conditions:

1. There should be sufficient heat put into the piece being welded so that at the end of the first pass the temperature will stay above or at least not go below the range of 125–175° C. before time has been allowed to start the second pass. If this can be accomplished by the use of the heat from the first pass only, then preheating is believed to be unnecessary. If the above conditions cannot be fulfilled, then sufficient preheat to fulfil the above condition will be necessary.

2. There should be sufficient heat put into the weld at the completion of the last pass so that the heat-affected zone will cool at a rate not to exceed 10–15° per second while traveling through the range of 500–650° C. It is obvious from this requirement that each pass would follow immediately after the previous pass.

## MACROSCOPIC EXAMINATION

An observation of Fig. 13 indicated that the effect of preheating was to increase the depth of the etched, heat-affected band directly adjacent to the weld. Number one and six weld beads show this quite well. In the sample shown at the left, this band appeared to be quite narrow and well defined while on the right, number one and six show a much broader heat-affected band and the bands did not appear as sharp and well defined. This was as expected. The difference in color of the heat-affected band from the base metal indicated a change in structure had taken place in the band. This change in structure took place above 700° C. With no preheat, the heat from welding was conducted from the weld by the base metal at such a rate that only a very narrow band adjacent to the weld-metal became heated to a temperature of 700° C. If the parent metal, however, was heated to 300° C. prior to welding the rate of heat flow from the weld was cut down considerably. This resulted in a wider band being heated to 700° C. than in the previous case. In the latter case, due to a lesser temperature gradient, the change in structure was more gradual. For this reason the heat-affected zone appeared to fade into the base metal. A sharp, well-defined heat-

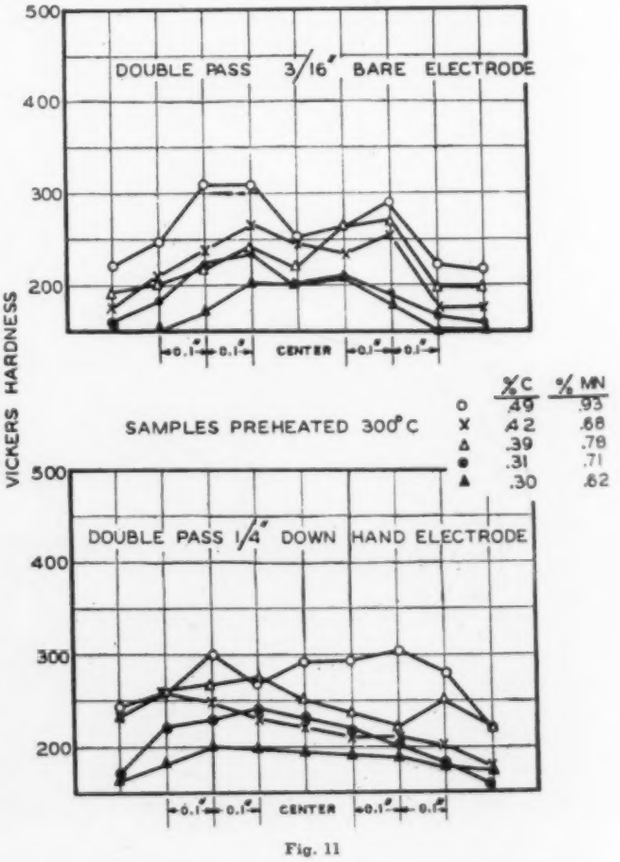



Fig. 11

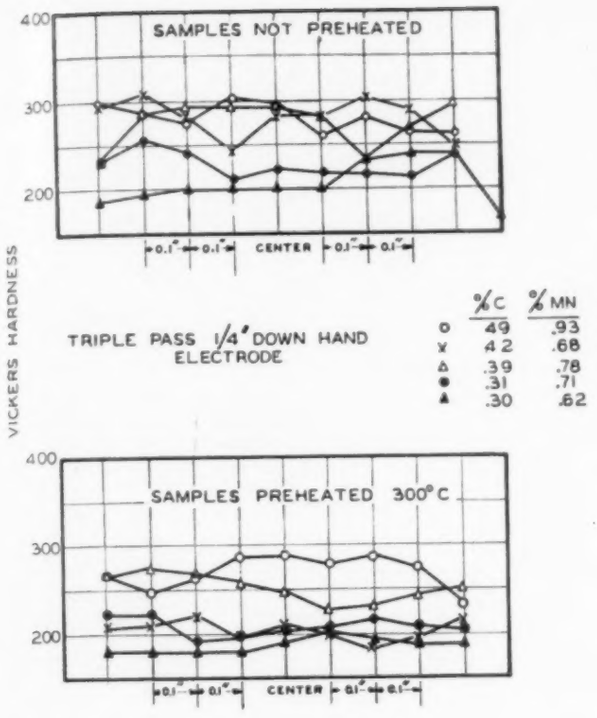



FIGURE 12

affected zone was the result of a very steep temperature gradient.

## MICROSCOPIC EXAMINATION

One of the purposes of this investigation was to study the effect of grain size on the physical and metallurgical properties of the weld. From the material used in this investigation, no definite results on grain size could be established. Of the five steels furnished, the two photomicrographs shown in Figs. 14 and 15, indicated the maximum contrast in grain size after furnace annealing at 1725° F. The fine grained material had a standard A. S. T. M. grain size of 5 to 7, while the coarse grained material had an A. S. T. M. grain size of 3 to 6. It was believed that this was not sufficient contrast in grain size.

From evidence of the effect of grain size in heat treating operations, it is believed that it would be better to use a fine grained steel in welding since such steel is not as susceptible to deep hardening as a coarse grained steel. This would mean that the heat-affected zone would theoretically be narrower in a fine grain steel than in a coarse grained steel. The above reasoning is illustrated in Fig. 16. Since transformation starts from the grain boundaries, and since the finer the grain size the larger the surface to volume ratio—(S/V), it follows that transformation will take place in a fine grain steel more rapidly than in one which is coarse grain. The difficulty in establishing any such definite conclusions experimentally is due to the very narrow region in which observations can be made. A fine grained steel in most instances will be definitely coarse at 1900° F. A coarse grain steel will almost always be fine up to a temperature of 1600° F. For this reason, observation is limited to the heat-affected zone between the isothermal lines of 1600 and 1900° F. The entire heat-affected zone does not usually exceed 0.10 inch in such instances where the austenitic grain size (evidenced as martensite) is outlined by a fine pearlite network. This being the case, the zone of 1900–1600° F. usually will not exceed a depth of one or two grains. For this reason conclusive results become difficult to obtain.

The two photomicrographs shown in Figs. 17 and 18 represent heat-affected zones from single-pass welds. At the left of each photograph the columnar structure of the weld-metal was observed. The right-hand side of each photograph shows the structure of the heat-affected zone. The zone consisted of martensite grains with ferrite and troostite at the grain boundaries. Though the grains were martensitic, the hardening power of the 0.3 per cent carbon steel was quite limited. In addition to this the steels were very nearly transformed to the low hardness products (dark etching constituents). Figure 18 indicates partial transformation of the martensite. This was indicated by the small needle-like particles throughout the light martensite grain.

From Figs. 19–22, it can be seen that the additional passes quite effectively broke up the columnar structure of the first deposited bead. In these figures also, the weld-metal can be seen at the left of each photograph and the heat-affected zone on the right. In all photographs shown in these figures, the heat-affected zone consisted of pearlite and ferrite. These photomicrographs also show up the fact that striking differences in the heat-affected zone due to differences in grain size are lacking.

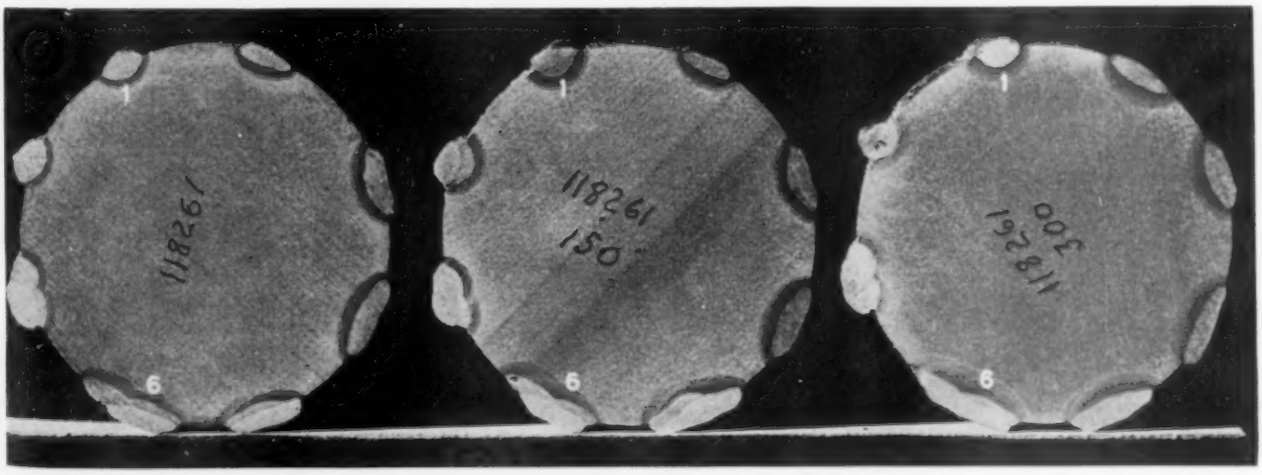



Fig. 13

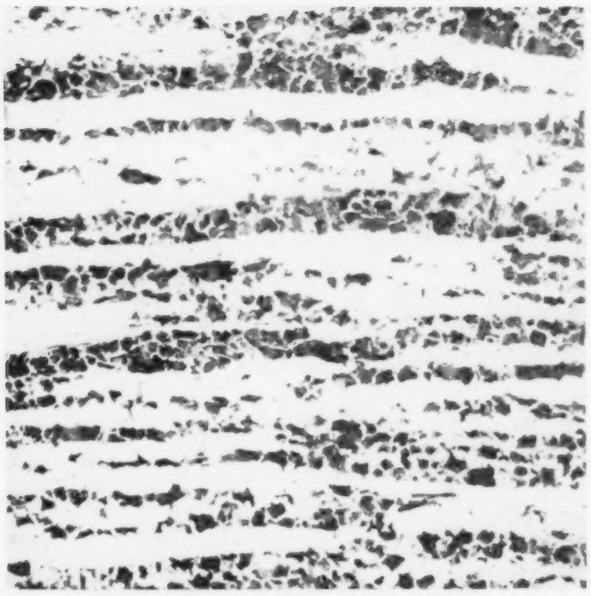


Fig. 14—S. A. E. 1030. Fine Grain Annealed 1725° F.—100 X

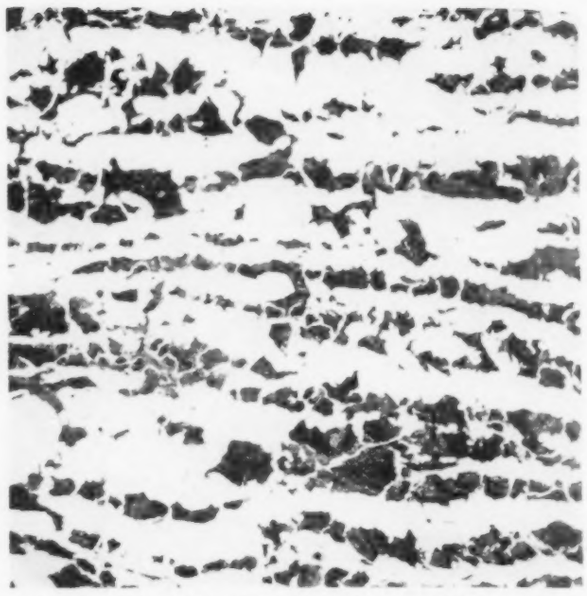


Fig. 15—S. A. E. 1030. Coarse Grain Annealed 1725° F.—100 X

Figures 23–26 illustrate some of the structures obtained when welding S. A. E. 1050 steel. Figure 23 shows the complete heat-affected zone of the base metal when welded with $^3/_{16}$-inch bare wire, using only one pass and no preheat. At the left is shown the edge of the weld-metal, showing the columnar structure, characteristic of a single-pass weld. The light-colored constituent adjacent to the weld-metal is martensite which is extremely hard. This material extends throughout the entire heat-affected zone. Receding from the weld, the martensite grains were noticed to be outlined by a dark constituent. This material was troostite. The martensite grains, as outlined by the troostite, were seen to decrease in size as the distance increased from the weld-metal. This was because of the lower temperature produced as the distance from the weld was increased. Finally, at the left-hand side of the photograph, large pearlite grains outlined by free ferrite were observed. This material was the unaffected parent metal.

Figure 24 illustrates the type of weld structure found when using a $^1/_4$-inch down-hand coated electrode, triple pass, and no preheat. Here the weld-metal had the polyhedral type grain structure which was caused from the annealing action of the additional deposited beads. The parent metal contained light-colored grains of martensite but considerable dark material (troostite) had been precipitated, thus this material was considerably softer than that shown in Fig. 23.

Figure 25 illustrates a single-pass weld with the typical dendritic or columnar structure. Here, as in the previous case, the martensite grain was bounded by troostite. There was, however, considerably more marten-

EFFECT OF GRAIN SIZE ON HEAT-AFFECTED ZONE

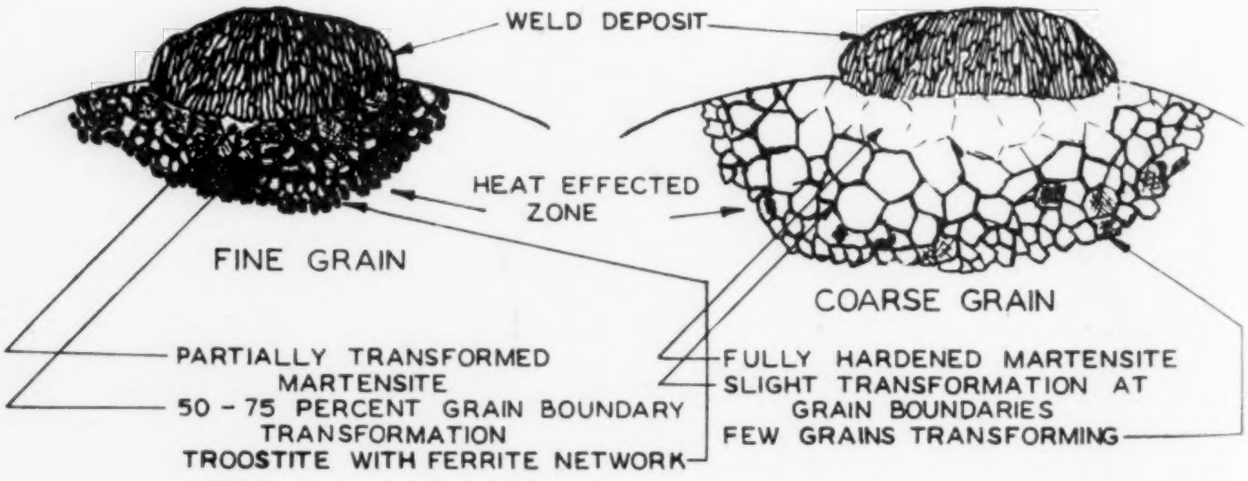



FIGURE 16

Fig. 17—S. A. E. 1030. Fine Grain Single-Pass Bare Electrode—100 X

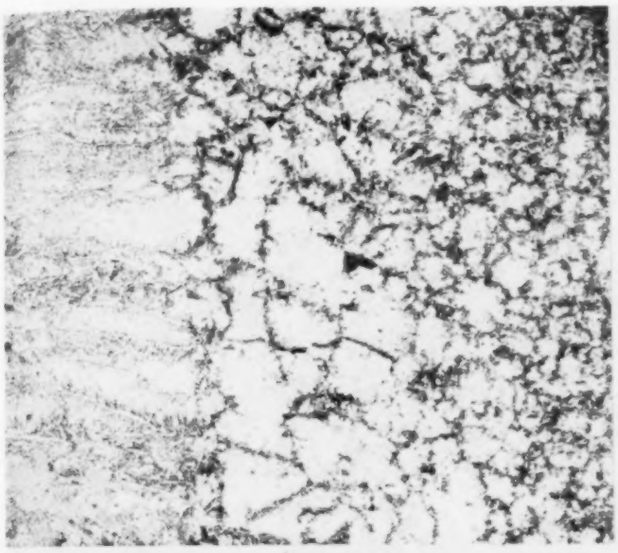
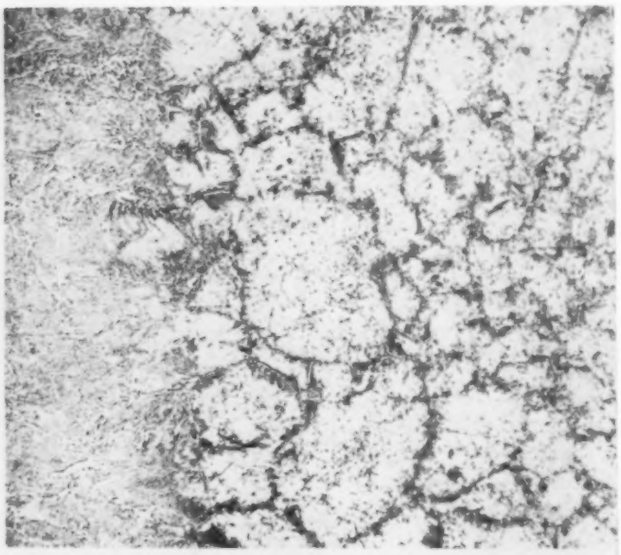


Fig. 18—S. A. E. 1030. Coarse Grain Single-Pass Bare Electrode—100 X



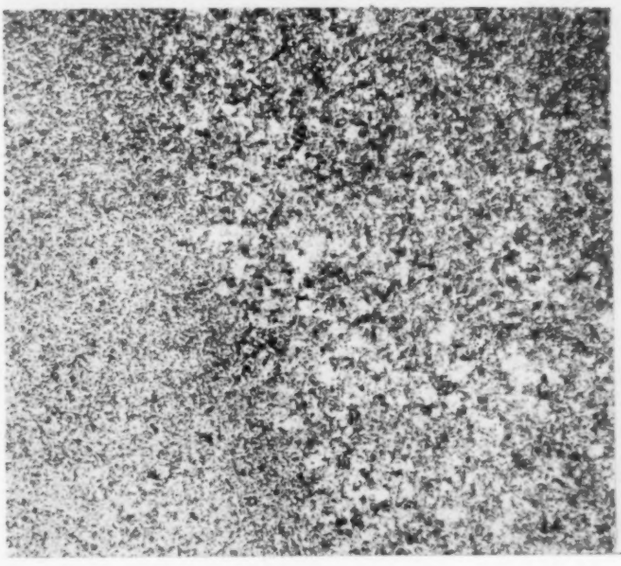


Fig. 19—S. A. E. 1030. Fine Grain 100 X. Triple Pass—1/4-Inch D.H. Coated Electrode

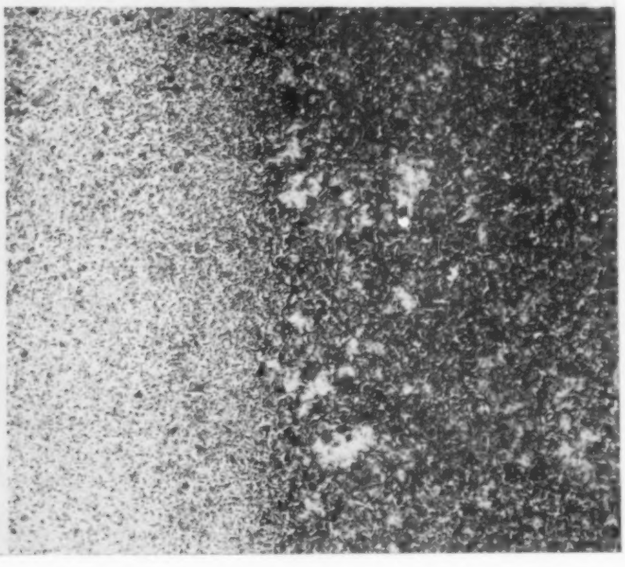


Fig. 20—S. A. E. 1030. Coarse Grain 100 X. Triple Pass—1/4-Inch D.H. Coated Electrode

site in this case than in the previous one, thus indicating that a single pass 3/16-inch bare wire weld and 300° C. preheat was not as effective in overcoming the hard constituents as was the 1/4-inch down-hand coated electrode, triple pass and no preheat.

Figure 26 illustrates the desired structure. The structure on the left is that of the weld-metal. Equiaxed grains were present, which was the result of the annealing action of the following beads which were deposited. The right-hand portion of the photograph shows the dark fine-pearlite structure containing a small amount of light "worm-like" ferrite. It was noticed that no martensite was present.

## STRESS RELIEVING

Though no tests were made on stress relieving it is believed to be a beneficial step in the welding of medium carbon steels (steels which are susceptible to hardening). It is also desirable that the welded material be placed in the stress-relieving furnace immediately after welding. If, after the last pass, insufficient heat has been put into the weld, the maximum cooling rate would have been exceeded with the result of small amounts of untransformed austenite remaining in the heat-affected zone. Immediate transfer to a stress-relieving furnace at a temperature of 1200–1400° F. would result in the untransformed austenite transforming at a temperature of some 300 to 400° C. depending on the rate of heating.

It is to be pointed out that in most instances, no disastrous results would occur if the welded construction could not be transferred to the furnace until cold. The untransformed material would merely transform at a temperature of 125–175° C. and the resultant weld would contain small quantities of martensite. The above statement is not to be confused with the fact that martensite formed after the first pass, when welding cold heavy plates, may give considerable difficulty. The difference lies in the fact that in one case only a very small amount of martensite is present and this is embedded in a soft matrix; in the latter case, however, the entire heat-affected zone becomes martensitic.

The resultant welded structure, after stress relieving, will be of a sorbitic-pearlitic nature, whether the structure is transferred to the stress-relieving furnace immediately after welding or allowed to cool to room temperature before being stress relieved.

Should small quantities of martensite be present in a welded structure and no stress-relieving treatment given, however, each small martensitic area would be a center of incipient cracks.

## CONCLUSIONS

1. The hardness and microstructure of the heat-affected zone of a weld on a given material is determined primarily by the rate at which the weld zone cools.

2. The welding current and welding speed (heat input) do not directly affect the structure of the heat-affected zone but indirectly affects the microstructure and hardness by influencing the rate at which the weld zone cools.

3. Plate thickness, or in general the shape and mass of the material should be given careful consideration before choosing the size of the electrode. This statement is made with special reference to choosing an electrode which will give the proper heat input for the given mass being welded. If a large electrode should be chosen to fulfil the above conditions, but if for some other reason it is not practical then preheating should be considered.

4. When welding medium carbon steels, if multiple-pass welding is to be used without preheating, sufficient heat should be put into the piece being welded, so that at the end of the first pass, the temperature of the heat-affected zone will stay in the range of 150–200° C. until time has been allowed to start the second pass (two to five minutes). At the completion of the last pass, there should be sufficient heat put into the weld zone to obtain a cooling rate which will not exceed 10–15° per second while traveling through the temperature range of 500–650° C.

5. When welding relatively heavy sections (probably

Fig. 21—S. A. E. 1030. Fine Grain Triple Pass—1/4-Inch D.H. Coated Electrode Preheated 300° C.—100 X

Fig. 22—S. A. E. 1030. Coarse Grain Triple Pass—1/4-Inch D.H. Coated Electrode Preheated 300° C.—100 X

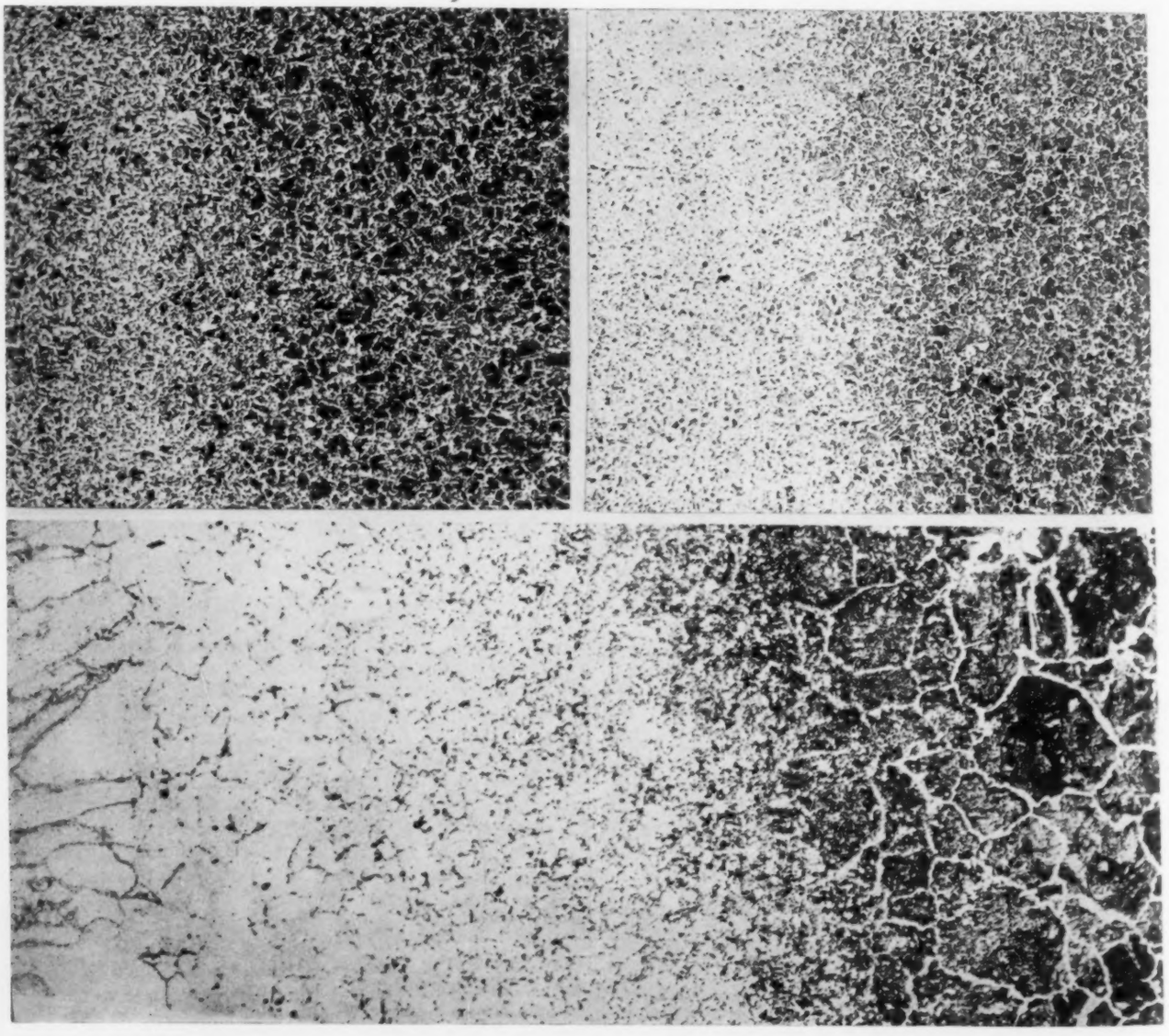
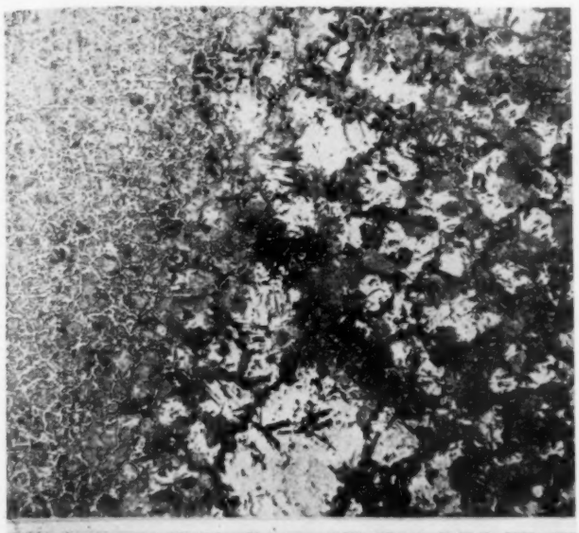


Fig. 23—S. A. E. 1050. Fine Grain Single-Pass Bare Electrode 100 X. Composite Photograph of Heat-Affected Zone

Fig. 24—S. A. E. 1050. Fine Grain 100X Triple Pass—1/4-Inch D.H. Coated Electrode



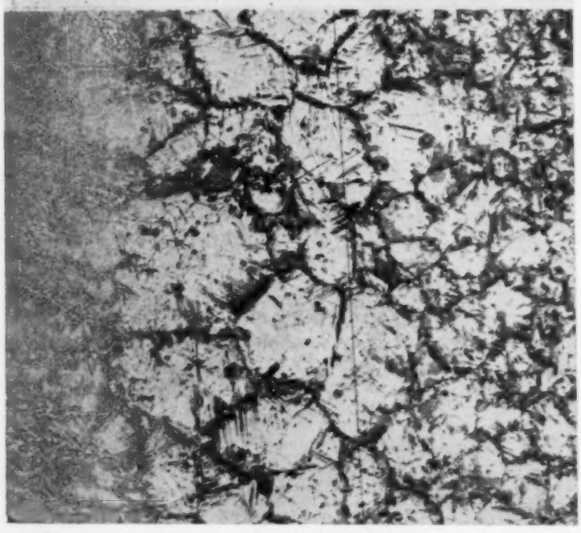


Fig. 25—S. A. E. 1050. Fine Grain 100X Single-Pass Bare Electrode Preheated 300° C.

3/4 inch or over) of 0.30–0.50 per cent carbon steel, it is recommended that a preheating temperature of 100–300° C. be used depending upon the number of passes to follow. The reason for preheating on the heavier sections is to be sure that after the first pass the temperature will remain above the critical temperature of 175–125° C. If heavy sections are welded without preheating they cool very rapidly to 100° C. and below, before the second pass can be made. This results in a critical condition and is believed to be the cause of a very large percentage of cracks which form after the first pass.

6. Conclusions based on the hardness results for 0.30 per cent carbon steel indicate that no particular difficulties would be encountered in the welding of this material with either bare or coated electrodes. Examination of the microstructure, however, revealed the presence of martensite, in the single-pass bare wire welds. It is known, on the other hand, that the hardness of martensite varies directly with its carbon content. In most cases it can be said that the use of preheating or the use of multiple beads for the purpose of supplying additional heat to 0.30 per cent carbon base metal is not required. If the weld is to stand high dynamic stresses it would be advisable to use 150° C. preheat in combination with a single-pass weld or else use at least a two-pass weld, the second pass following immediately after the first.

7. In the case of welding both 0.40 and 0.50 per cent carbon steel, a single-pass weld should probably not be used on sections of 1/2 inch or thicker, unless a preheating temperature of 300° C. is used. If several layers are to be deposited which will gradually build up the temperature in the weld zone, then it is necessary only to preheat to possibly 100° C. (Sufficient heat to be above 150° C. after the first pass has been deposited and until such time as the second pass is started.) When welding 1/4-and 3/8-inch material, the heat from the first pass is believed to be sufficient to keep the plate at the desired temperature until the second pass can be started. For this reason preheating is probably unnecessary for 1/4-and 3/8-inch material. Hardness values were obtained on the 0.50 per cent carbon steel which varied from 760 to 225 Vickers depending upon the rate at which the weld zone cooled.

8. Microscopic examination of the steels investigated revealed a wide variety of structures. The structure of the heat-affected zone of a single-pass bare wire weld deposited on S. A. E. 1050 was found to be fully martensitic. In contrast to this, however, a fine pearlitic-sorbitic structure was obtained in the heat-affected zone of welded S. A. E. 1050 steel which had been preheated to 300° C, followed by a triple-pass weld made with a 1/4-inch coated electrode.

9. No definite conclusions could be established on grain size from the results obtained in this investigation. From a theoretical viewpoint, however, it would seem that a fine-grain steel would be more suitable for welding than a coarse-grain steel.

10. Stress relieving is considered beneficial in the welding of medium carbon steels.

## ACKNOWLEDGMENTS

The author is indebted to Mr. C. H. Jennings, engineer in charge of welding research, Westinghouse Research Laboratories, and Dr. A. Allen Bates, Manager, Chemical and Metallurgical Division, Westinghouse Research Laboratories, for their cooperation and constructive criticism during the preparation of this article. The author also wishes to express appreciation to Miss Mildred Ferguson, Westinghouse Research Laboratories, for the metallographic studies.

Fig. 26—S. A. E. 1050. Fine Grain 100X Triple Pass—1/4-Inch D.H. Coated Electrode Preheated 300° C.

# THE METALLURGICAL ASPECTS OF Resistance Welding Electrodes*

By R. H. HARRINGTON†


## ABSTRACT

*The history of the metallurgical development of resistance welding electrodes is given. Present electrode alloys are classified in four divisions based on applications. The general requirements of an electrode material are defined. Future problems are listed. Further developments appear to be dependent upon the class of materials known as "precipitation-hardening alloys."*


## INTRODUCTION

WHILE a lecturer at the Franklin Institute in the winter of 1876–1877, Professor Elihu Thompson noted several phenomena, the study of which led him to important developments, one of these being the principle of electric welding. When electric current is passed through metals, they are heated in direct proportion to the magnitude of their resistance. The resulting temperatures can be controlled so accurately that, with the pressure of the electrodes squeezing the parts together, consistently strong welds are produced. The parts which apply the electric current and the pressure to the materials to be welded are known as electrodes. The early requirements of high conductivity for such electrode material made copper the logical choice. High production levels, however, have made copper obsolete, for pure copper is soft and will not withstand modern requirements without quickly deforming or "mushrooming."

## HISTORICAL DEVELOPMENT

With the first requirements of high electrical conductivity and availability, copper was initially the logical material for resistance welding electrodes. However, with the pressures required to hold the work together for the production of good welds, it was readily apparent that annealed copper had far too low a proportional limit. Soft copper electrodes deformed under too light pressures and the impact of early manually-controlled welding machines, thus altering the contact area of the electrode and altering the character and quality of the weld produced. It was, of course, well known that copper could be materially strengthened by cold working with very little loss in conductivity. Thus, cold drawn copper rod became widely used for spot-welding electrodes and cold-rolled copper plate for seam-welding wheels.

The high cost of maintenance and replacement of work-hardened copper electrodes in high-production lines spurred on the search for better electrode materials. It was soon apparent that the high electrical conductivity of plain copper was not required. It was also known that solid solution alloys work-harden to a greater extent than will pure metals. The first small additions of solid soluble metals have the greatest effect in lowering the conductivity of the solvent or base metal and the degree of this effect varies with, and is characteristic of, the added metal element. "Cut-and-try" procedure resulted in the development of several suitable solid solution alloys. Of these, the alloy of 1% of cadmium in copper is typical and was easy to fabricate into rod and plate, possessed excellent electrode properties for wide use in the resistance welding of plain carbon and alloy steels as well as non-ferrous alloys, and became a generally used and economical electrode material.

Further increase in the rates of production, coupled with the inherent properties of the materials to be resistance welded, soon resulted in four main divisions of resistance welding materials as follows: (1) plain carbon steels, (2) stainless (or alloy) steels, (3) non-ferrous alloys such as brasses and bronzes and (4) the resistance welding of copper, itself. Just as in the field of the machining of metals, a number of tool alloys find specific applications so, in these four classifications of resistance welding materials there was the apparent possibility of more specific application of a number of electrode materials differing rather widely in their inherent properties.

Methods of powder metallurgy offered means of fabricating mixtures of metals that do not appreciably alloy with one another. Two general methods are as follows: (1) press together in a mold fine powder mixtures of the desired metals and sinter the pressed object in hydrogen at a temperature just below or just above the lowest melting point, as the case may be, or (2) press in a mold the powder of the metal having the highest melting point, remove and soak it in molten metal having the lower melting point. The resulting product will resist deformation better than will the pure softer metal and will have an electrical conductivity dependent upon the proportional conductivities of the metals in the mixture and the density of the pressed product (higher conductivity with greater density). In this manner were produced pressed and sintered mixtures of tungsten with copper and with silver. The fabrication method has limitations as to applications and these mixtures are inherently of relatively high value. Economy and fabrication problems led to brazing tips of these materials to plain copper bases for spot and projection welding electrodes. Some specific applications for these electrodes, of lower electrical conductivity, are general resistance welding of stainless steel, projection welding of plain carbon steel, and resistance welding of phosphor-bronze. The life of these electrodes justified their use in these specific applications.

In comparatively recent years, the class of alloys, known as "precipitation-hardening," has been subjected to detailed study resulting in a better understanding of the reactions involved. Copper is constituted of but one phase, crystals or grains of Cu, no matter what one

* Paper to be presented at Annual Meeting, A. W. S., Detroit, Mich., Oct. 16 to 21, 1938. Contribution to Fundamental Research Division of Welding Research Committee.

† Research Metallurgist, General Electric Company, Schenectady, New York.

may do to it in the solid state in the way of heat treatment. Similarly, the alloy of 1% of Cd in Cu is constituted of but one phase, a solid solution of Cd in Cu, at all temperatures from room temperature to its melting point. As an example, the Cu-Be system is one in which the solid solubility of beryllium in copper *increases* with increase in temperature in the solid state. Thus, copper dissolves only about 1% of beryllium at room temperature as compared with 2.7% beryllium in solution at about 875° C., just below the melting point of the alloy. This means that, as the standard 2.25% Be alloy cools slowly from solidification down to room temperature, about 1.25% of Be is thrown out of solution as a second phase, corresponding to the compound, CuBe. The alloy cooled slowly, however, has poor physical properties. These may be brought to a maximum by water quenching this composition from about 850° C. which retains all of the Be in a solid solution at room temperature. This solid solution is supersaturated, of course, as it has an excess of 1.25% Be in solution. By reheating for the proper time in the temperature range of 275–350° C. the excess Be is precipitated as the second phase in a critical particle size. This results in an increase in proportional limit, tensile strength, hardness and *electrical conductivity* and a decrease in elongation. Thus, the Cu-Be alloys from 1% Be to 2.75% Be are "precipitation-hardening."

The standard 2.25% Be-Cu alloy has a conductivity of about 18% of that of copper in the solution-quenched condition as compared to a maximum of 37% in the *precipitation-hardened* state. This conductivity is not quite high enough for sufficiently wide application as a resistance welding electrode and it operates as such successfully only for a few electrode applications under special conditions. However, two ternary alloys‡ have been developed that are very successful as resistance welding electrodes. One of these is an alloy of 0.4% Cr, 0.1% Be and 99.5% Cu that yields an electrical conductivity of over 70% combined with a proportional limit of 35,000 lb./sq. in. The other alloy is constituted of 2.6% Co, 0.4% Be, 97% Cu and combines an electrical conductivity of 55% with a proportional limit of 45,000 lb./sq. in. These two ternary alloys serve as resistance welding electrodes for all steels, plain carbon and alloy steels. It is apparent that there may be a number of such alloys that will serve well as electrodes but these two compositions are given merely as examples. It appears that future development of better electrodes lies in this field of precipitation-hardening alloys.

The table summarizes the typical compositions with their physical properties and several conclusions may readily be drawn by inspection.

1. Alloys such as No. 5 will largely displace the pressed powder compositions for resistance welding of steels because of superior properties and greater ease of fabrication.
2. Alloys such as No. 4 and No. 5 represent the latest development of precipitation-hardening alloy electrodes for the resistance welding of plain carbon and alloy steels.
3. Superior control mechanism is required in high speed production resistance welding to obtain the maximum life with the precipitation-hardening alloy electrodes so that alloys, such as No. 3, will probably always find some electrode applications.
4. Plain copper should find use only in small shops for odd jobs where life of the electrodes is not a major cost factor. There are also some natural applications in welding non-ferrous alloys.
5. The class of material to be welded will determine which type of electrode may be used with maximum efficiency.

## CHARACTERISTIC PROPERTIES OF RESISTANCE WELDING ELECTRODES

There are two classes of properties: (1) indirect, or alloy properties, that determine the methods of fabrica

‡ Described in detail in "Precipitation-Hardening and Double-Aging," by R. H. Harrington, *Metals Technology*, Dec. 1936. *A. I. M. E. Tech. Pub. No. 759.*

TYPES OF RESISTANCE WELDING ELECTRODE MATERIALS

| ALLOYS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| TYPE NO. | TYPICAL COMPOSITION | CONDITION | HARDNESS ROCKWELL B | PROPORTIONAL LIMIT SQ. INCH | ELECTRIC CONDUCTIVITY | MAXIMUM SERVICE TEMPERATURE | TENSILE STRENGTH SQ. INCH | % ELONGATION | BRINELL HARDNESS |
| 1 | 100% Cu | ANNEALED | TOO SOFT | 5,000 | 100% | TOO LOW | 32,000 | 38 | 44 |
| 2 | 100% Cu | COLD ROLLED | 58 | 12,000 | 98% | 150°C | 50,000 | 18 | 90 |
| 3 | 99 Cu - 1 Cd | COLD ROLLED | 65 | 27,000-30,000 | 85% | 200°C | 60,000 | 20 | 115 |
| 4 | 99.5 Cu - 0.4 Cr - 0.1 Be | HEAT TREATED | 76 | 35,000-37,000 | 75% | 350°C | 55,000 | 15 | 140 |
| 5 | 97 Cu - 2.6 Co - 0.4 Be | HEAT TREATED | 94 | 45,000 | 55% | 400°C | 110,000 | 20 | 220 |
| PRESSED POWDER MATERIALS | | | | | | | | | |
| 6 | 50 W - 50 Cu | | 50 - 77 | | 39% | DATA SHOWS VARIATION IN CONDUCTIVITY AND HARDNESS WITH VARIATIONS IN COMPOSITION | | | |
| 7 | 70 W - 30 Cu | | 85 - 93 | | 34% | | | | |
| 8 | 81 W - 19 Cu | | 100 - 106 | | 26% | | | | |
| 9 | 75 W - 25 Ag | | 90 - 98 | | 45% | | | | |
| 10 | 100 % W | | 102 - 112 | | 28% | | | | |

tion of the electrodes, and (2) direct properties which determine the performance of the material as an electrode.

Indirect alloy properties are those such as foundry properties, forgeability, sinterability of powders, machinability, heat treating, brazing, etc.

Direct electrode properties appear to be four in number: (1) electrical conductivity, (2) resistance to "mushrooming" or resistance to plastic deformation, (3) maintenance of resistance to plastic deformation at elevated temperatures and (4) an undefined property which may prove to be surface contact resistance.

## DIRECT PROPERTIES OF RESISTANCE WELDING ELECTRODES

1. *Electrical Conductivity.*—It was at first assumed that high electrical conductivity was a primary requirement but high production emphasized the necessity of long life electrodes with good resistance to deformation at the electrode contact surface. When minimum electrode conductivities have been determined for welding specific materials then electrodes with better strength properties can be developed. These minimum conductivities will depend upon the nature of the material being welded, clean or scaled surfaces, thickness of parts to be welded, type of resistance welding such as seam, spot, projection or flash welding, etc.

Some examples are as follows:

The standard 2.25 Be-Cu alloy with 37% of the electrical conductivity of copper is almost satisfactory for spot and seam welding of stainless steel while alloy No. 5, with 55% conductivity (45% when used as heat-treated castings) performs very well. Thus, it would seem that, generally, a minimum conductivity of 40% is required for these applications.

Similarly, Alloy No. 5 will perform well in only a few cases in the seam and spot welding of plain carbon steel while Alloy No. 4 with 75% conductivity performs very well. One would be tempted to place the minimum electrode conductivity for these applications at 65% of that of copper.

A different case, entirely, is that of the fusion resistance welding of copper, itself. Here electrical conductivity of the electrode material is of secondary importance. For this application the electrode material must have a considerably higher melting point than that of copper and must be incapable of alloying with copper to any appreciable degree. The metal, tungsten, with only 28% conductivity, meets these requirements.

Another interesting property is that exhibited by some of the precipitation-hardening alloys. Their electrical conductivity decreases, with increase in temperature, at a lesser rate than does that of pure copper. Thus, Alloy No. 4, with an electrical conductivity of about 75% at room temperature, actually has an electrical conductivity of 85% (of that of Cu) at 125° C.

2. *Resistance to "Mushrooming"—or Proportional Limit.*—For years the term "hardness" has been used so generally that, unconsciously, we have come to regard "hardness" as being a simple, single property like "tensile strength" or "elongation," etc. Actually "hardness" is partly a measure of work-hardenability of a metal or alloy when it is plastically deformed *above* its elastic limit. It is quite possible for two alloys to have the same elastic limit and different "hardness." Similarly, two alloys with the same "hardness" may have widely different elastic limits.

It is constantly the aim to develop, and to use, electrode materials with a high *elastic limit* so that they will *not* deform or "mushroom" in service. The hardness test measures an effect that takes place largely *above* the elastic limit. Therefore, hardness tests should *not* be used to compare two *different* alloys as to their resistance to "mushrooming." However, the hardness test can be used to show whether each individual alloy has reacted properly to heat treatment or to cold working.

Fundamentally, the elastic limit should be used to determine the resistance to "mushrooming" of an electrode alloy. To measure the elastic limit is a more difficult and costly procedure than to measure the *proportional limit.* The proportional limit is that load value above which further stressing will result in greater than proportional strain. The proportional limit, generally, is appreciably below, but may be close to, the elastic limit. The accuracy of measurement of the proportional limit is determined by the accuracy of the extensometer used for the test. (All proportional limits reported in the table were measured by use of the Sayre extensometer.)

It is possible for an electrode alloy to have too high an elastic limit (or "hardness") for certain applications. If the electrode is too rigid in some applications it may mark the surface of the material being welded to such an extent that necessary coatings for that surface will not mask the electrode mark from the eye of the customer.

Generally, however, it is desirable to have high elastic (or proportional) limits in resistance welding electrode alloys. (It is apparent that tensile strength is of no importance.)

3. *Resistance to the Effect of Temperature.*—In spite of the fact that, wherever possible, spot-welding electrodes are water cooled and seam-welding wheels operate in a constant flow of cold water, the contact faces of electrodes are subjected, at least momentarily, to relatively high temperatures. What these temperatures may actually be, depends upon (1) material being welded, (2) dimensions of material being welded, (3) welding apparatus in use and (4) local welding technique.

The maximum temperature to which an alloy may be heated for long periods of time and recooled to room temperature without appreciable loss of room temperature physical properties is probably the best test to indicate an alloy's resistance to temperature effects in the application as a resistance welding electrode.

Metals and alloys, such as No. 2 and No. 3 in the table, depending upon cold work alone for their physical properties, generally become "dead soft" or annealed when heated above their recrystallization temperatures. Thus, cold-rolled copper and the alloy of 1% Cd in Cu will recrystallize at temperatures in the range of 300 to 450° C., depending upon the amount of cold working they have undergone: the greater the amount of cold work applied, the lower is the recrystallization temperature. Cold-worked metals and solid solution alloys are actually in a metastable condition and will appreciably lose their properties, in the cold-worked state, at service temperatures considerably below their temperatures of recrystallization. These allowable service temperatures will vary for different materials, being about 150° C. for cold-worked copper and may be as high as 200° C. for the cadmium-copper alloy.

Precipitation-hardening alloys generally have service temperatures, depending upon the particular alloy, that may be only a little below their precipitation-hardening temperatures. Thus, Alloy No. 5 precipitation-hardens at 500° C. and, from a variety of applications, appears to have a service temperature of 400° C.

A certain few precipitation-hardening alloys, even when fully hardened, are still soft enough and have sufficient ductility to have their properties further improved by subsequent cold working. Since these alloys have

been fully precipitation-hardened previous to cold working, the large number of minute particles of the hard precipitated phase obstruct the diffusion reactions involved in recrystallization, resulting in a higher recrystallization temperature and higher service temperatures. Thus, Alloy No. 4 is precipitation-hardened (after the solution quench) at 500° C., and is then cold worked to finish dimensions in rod and plate stock. In *this* condition it does not apparently recrystallize below 500° C. and a wide variety of applications seem to indicate that its service temperature is about 350° C., quite a bit higher than service temperatures for cold-worked metals and simple solid solution alloys.

4. *The "X" Property* (possibly surface contact resistance).—Sufficient electrical conductivity, suitable resistance to "mushrooming," and high service temperature do not necessarily qualify an alloy as a good resistance welding electrode material.

For example: Alloy No. 5 is an excellent electrode for the resistance welding of stainless steel. If 0.2% of aluminum is substituted for 0.2% of the beryllium, the resulting alloy has practically identical tensile properties, electrical conductivity and resistance to temperature effects. This alloy, containing aluminum, sticks to the material being welded and is, therefore, *not* suitable for resistance welding electrodes. The property involved has not been clearly defined but it may be that the contact surface resistance is too high due, possibly, to an oxide film. Until this property, whatever it may be, is clearly defined, it will be necessary to make "cut-and-try" welding tests throughout the full range of control in available welding equipment before accepting or rejecting new alloys as welding electrode materials.

## ELECTRODE ALLOY VS. MATERIAL TO BE WELDED

It can now be said that certain classes of metallic materials can be welded with the use of certain types of metal or alloy electrodes. Specific electrode compositions, however, must be chosen by actual trial under the practical conditions of: (1) welding equipment available, (2) control equipment available, (3) local welding technique and (4) physical condition of the material to be welded. Obviously, then, the relationships discussed below are merely metallurgical aspects of resistance welding electrodes and not definite practical recommendations of specific electrode alloy compositions. The table of Electrode Materials lists only single examples of each type of electrode material as representative compositions.

As previously noted, materials that are being resistance welded may be classified as follows: (1) plain carbon steels, (2) stainless (or alloy) steels, (3) non-ferrous alloys and (4) plain copper. There are also the different forms of resistance welding: (1) spot welding, (2) seam or line welding, (3) projection welding and (4) flash welding.

1. *Plain Carbon Steel.*—These require higher conductivity electrodes than do the stainless steels, with the exception of projection welding and flash welding. Electrode types 3 and 4 are justified for spot and seam welding. Type No. 5 is satisfactory for projection welding and flash welding while several bronze compositions having electrical conductivities of 10–20% are also suitable for flash-welding dies. Plain carbon steels are generally spot and seam welded under sufficient pressures to make good welds at temperatures just below the melting ranges of the steels.

2. *Stainless and High-Alloy Steels.*—These do not require as high an electrical conductivity in the electrode as do the carbon steels. Alloys of Type No. 5, with conductivities over 40% of that of plain copper and with higher proportional limit, give maximum service for all forms of resistance welding of stainless steels. Some of the pressed and sintered powder mixtures of tungsten with copper and with silver are also quite satisfactory. The stainless steels also weld under proper pressures in the solid state at temperatures just below their melting ranges.

If it were necessary to fusion resistance weld the steels as in the case of many non-ferrous alloys, the molten steel in contact with copper base alloy electrodes would very likely alloy with and stick to such electrodes. This would probably necessitate the use of electrodes of the type of pressed powder mixtures of tungsten with copper or with silver or plain tungsten, itself, and, even then some alloying difficulties with these electrodes might result.

3. *Non-Ferrous Alloys.*—Most of these alloys, unlike steels, will not forge weld or weld under pressure in the solid state in air atmospheres at any temperature because of the tenacious characteristics of the oxide films formed on the surfaces of these alloys when they are heated in air. Consequently most of these alloys must be fusion resistance welded.

Certain alloying elements, with any given base metal, will obstruct the alloying diffusion of other metals into the solid base metal alloy. Detailed information regarding this effect is almost entirely lacking for electrode alloys so that electrode applications for welding this class of alloys are almost entirely "cut-and-try" results.

Also, the interfacial contact resistance of the materials to be welded may be sufficiently high to cause fusion of these surfaces in a time too short to melt entirely through the parts to be welded so that contact of electrodes with these molten alloys can be avoided. In such cases, accurate timing control apparatus will greatly lengthen the life of electrodes and may even be the determining factor in making successful welds. Accurate data as to the interfacial contact resistances of these materials (to be welded) have either not been published or are entirely lacking.

Some electrode applications for welding such materials are as follows: Type No. 3 for brass, pressed and sintered mixtures of tungsten with copper or with silver for welding phosphor-bronze, Type No. 3 for certain aluminum base alloys, etc. Pure tungsten (No. 10) and cold-rolled copper (No. 2) find some applications.

4. *Fusion Welding of Pure Copper.*—In this case, the electrical conductivity of the electrode alloy is secondary in importance to the ability of the electrode material to withstand the temperature of molten copper without alloying with the copper. For metal electrodes, the use of pure tungsten is practically mandatory. (This report is not concerned with the use of graphite contacts for the chief purpose of resistance heating, as in some forms of brazing.)

## FUTURE PROBLEMS

The chief aims of this report are: to describe the trend of metallurgical progress in resistance welding electrode alloys, not to determine but to point out the need for clear definition of desirable electrode properties, to stimulate metallurgical interest in resistance welding electrodes as well as in the actual resistance welding, and to list some of the problems for immediate future research. Some of these immediate problems are the following:

1. To more accurately define the requirements of resistance welding electrodes for different applications. In this connection, while four chief properties were discussed individually above, each of these is not necessarily independent of some of the others and there may still be further desirable properties as yet undefined.

2. Development of more efficient electrode alloys

which, almost from necessity, will probably come from the class of alloys known as "precipitation hardening."

3. Measure the contact surface resistances of electrode materials under various conditions: sand-blasted, filed, tool machined, pickled, buffed and with controlled thicknesses of oxide scale or films.

4. Measure the contact surface resistance of the materials to be welded, individually and in combinations (if possible) and also the relative effect of temperature on these values. (Similar to No. 3).

5. Development of special alloy electrodes for specific combinations of non-ferrous alloys to be welded, electrode alloys that will resist specific diffusion into the electrode by the molten alloy (to be welded).

### CONCLUSIONS

1. The metallurgical history of the development of resistance welding electrodes is given.

2. Definitions of desirable electrode alloy properties are attempted to facilitate discussion and further development. These are: (1) suitable electrical conductivity, (2) high proportional limit, (3) maintenance of physical properties at as high a service temperature as possible, (4) the "X-property," probably contact surface resistance.

3. Resistance welded materials are classified in four general divisions: (1) plain carbon steels, (2) stainless or high-alloy steels, (3) non-ferrous alloys such as brasses, bronzes and aluminum base alloys, (4) the fusion welding of copper.

4. It seems highly probable that future development of new resistance welding electrode alloys will lie in that class known as "precipitation-hardening alloys."

5. Five problems of immediate interest are suggested for research, the results of which will aid greatly in the development of new electrode alloys and in the scientific understanding of resistance welding phenomena.

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# STRESS DISTRIBUTION IN WELDS

## Subject to Bending*

By CYRIL D. JENSEN† and ROBERT E. CRISPEN‡

### INTRODUCTION

THE investigation reported herewith has been designed to clarify an apparent lack of agreement between current theories on the distribution of stresses in a welded connection subjected to bending. Figure 1 shows the problem graphically, the upper sketch showing the basic problem, and the lower sketch a practical application. The two theories are those advanced by Prof. T. C. Shedd in his book STRUCTURAL DESIGN IN STEEL,[1] and Mr. N. G. Schreiner in his paper BEHAVIOR OF FILLET WELDS WHEN SUBJECTED TO BENDING STRESSES.[2]

* Paper to be presented at Annual Meeting, A. W. S., Detroit, Mich., Oct. 16 to 21, 1938. Contribution to Fundamental Research Division of Welding Research Committee.

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‡ Former student at Lehigh University.

[1] John Wiley & Sons, Inc., Publishers.

[2] AMERICAN WELDING SOCIETY JOURNAL, Sept. 1935.

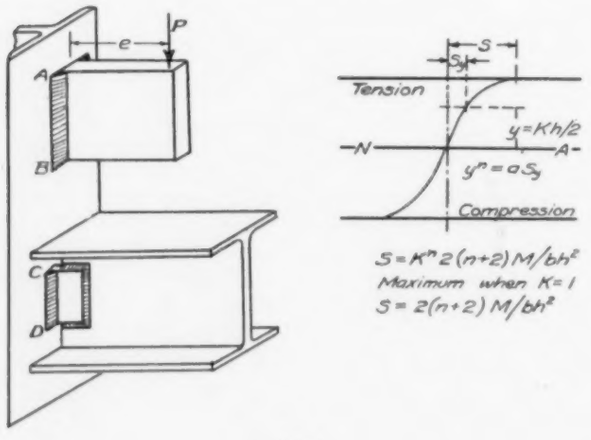



Fig. 1

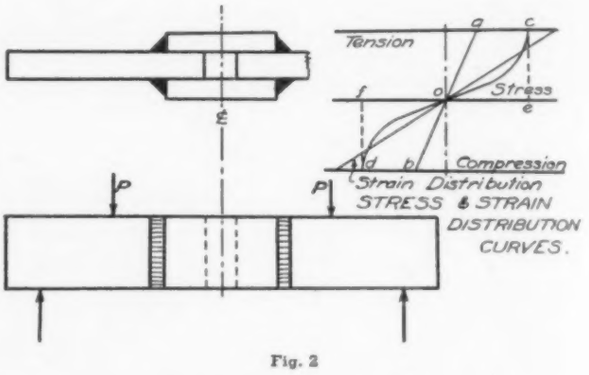


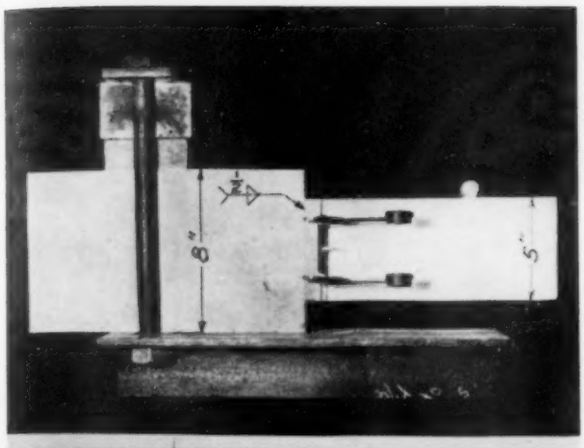

Fig. 2

### CURRENT THEORIES

Prof. Shedd states that at abrupt changes of section as points *A*, *B*, *C* & *D*, Fig. 1, the straight line concept of stress distribution does not hold, but that higher stresses obtain at the extremities of the weld. He suggests a general equation of the stress distribution as follows: $y^n = as_y$ and derives a more specific equation for the stress in the extreme fibers, $s = 2(n+2)M/bh^2$, where $n$ must be determined experimentally. He suggests that for joints subjected to repeated loadings, such as brackets for a crane runway, a value of 4 be used for $n$. This doubles the computed fiber stress due to bending over that obtained by the regular flexure formula.

Mr. Schreiner, whose research work has to do mainly with ultimate loads, assumes the straight-line distribution of stress for loads below the yield point, as given by line *aob* in Fig. 2. At loads slightly above the yield point the curve *cod* represents the stress distribution. His reasoning is as follows: As the outermost fibers reach yield point they stretch without increase in stress, and succeeding fibers (toward the neutral axis) also reach

Fig. 3A



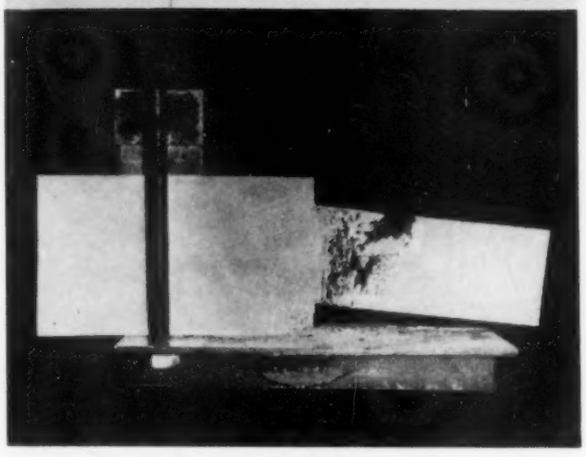


Fig. 3B

the yield-point stress. As the load is increased successive fibers approaching the neutral axis reach the yield-point stress until the final distribution is represented by *ceofd*. This final distribution results in a section modulus of $bd^2/4$ instead of the customary $bd^2/6$. He points out that ultimate loads can be predicted more closely by using the former value rather than the latter. However, in his conclusions he does not advocate the use of the former value for design purposes.

Mr. Schreiner's method of computing the resistance of the welds is interesting and is worth discussing. The usual method is to equate the bending moment, $M$, to the resisting moment, $SI/c$, where $S$ is the stress in lb./square inch, $I$ is the moment of inertia in inches,[4] and $c$ is the distance $d/2$ where $d$ is the depth of the member. $I/c$ is called the section modulus and reduces to $bd^2/6$ for rectangular sections where $b$ is the width of the member in inches. In the simplified method $S$ is the safe load per inch of fillet weld, its value for covered electrodes, according to the recent revision of the A. W. S. building code, being 1200 lb. per eighth inch of leg of fillet. Accordingly, $^1/_4$-inch welds carry a safe load of 2400 lb./inch, etc. The section modulus for one line of weld becomes $d^2/6$ and for two lines of weld is $d^2/3$. Thus, if a moment is given and the size of the weld is assumed, with its consequent safe load per inch of weld, the required length of weld is easily computed. Or the length of weld may be assumed and the required size of weld determined.[3]

[1] For a more detailed discussion of this subject the reader is referred to a paper, DESIGNS INVOLVING FILLET WELDS by C. D. Jensen in the AMERICAN WELDING SOCIETY JOURNAL, Jan. 1937, and to another paper, THE PRACTICAL DESIGN OF WELDED STEEL STRUCTURES by Malcom Priest in the same Journal under date of August 1933.

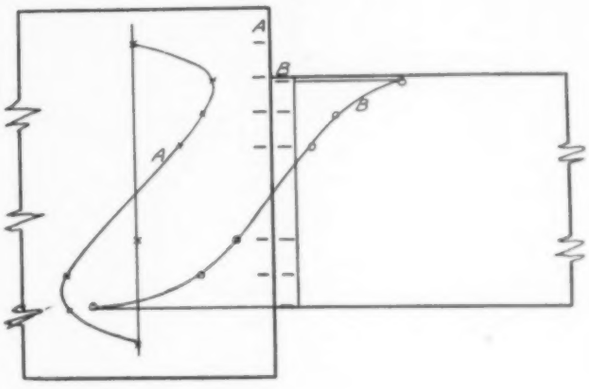
It may appear that the two theories just outlined are not compatible. However, Prof. Shedd's study is in the realm of repeated loadings below the yield-point stress while Mr. Schreiner's investigation has to do with ultimate loads and must be assumed as being for static loads as his theory is based upon conditions above the yield point.

The undergraduate thesis by Crispen involved both a polarized-light study and actual tests on steel specimens in which the welds were machined to exact size. The polarized-light studies gave interesting data, but not particularly pertinent; on the other hand, the steel specimen tests gave most unusual information. This report, as a consequence, will be confined to these latter tests.

## STEEL SPECIMEN TESTS

Fig. 3*A* shows a specimen whitewashed and ready to be tested. A pair of Huggenberger tensometers is occupying a similar position on the reverse side of the specimen. A $^1/_2$-inch gage length was used which nearly spanned the diagonal faces of the $^1/_2$-inch machined welds. Strains were also measured along the vertical edge of the base plate (line *A* in Fig. 4). The results have been plotted graphically for both lines *A* and *B*, the graph for *A* being offset to the left for clearance. This strain distribution is typical for all three specimens tested, one of which was stress-relieved. Further, the curves are typical for loads both above and below the yield point. It will be noted that the data confirm

Fig. 4



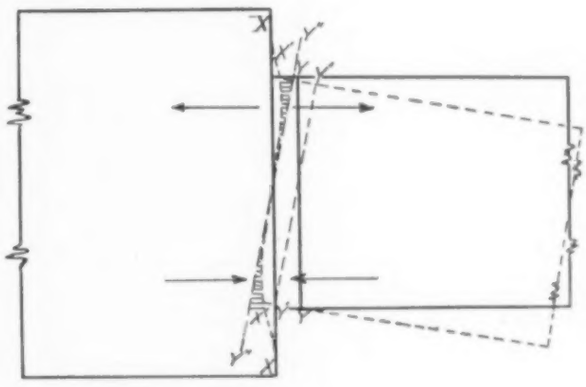



Fig. 5

the Shedd theory for loads below the yield point where stress is proportional to strain. But when the loads are increased to the yield point the strains may differ greatly yet the stresses may all be at the yield point, except for a few fibers near the neutral axis.

One is inclined to state, therefore, that Shedd's curve of stress distribution for loads below the yield point and Schreiner's curve of stress distribution above the yield point are correct, but that Schreiner's assumed curve below the yield point is incorrect. However, it will be observed that Schreiner's specimens (Fig. 2) and those used in this investigation differ in one particular detail. In Schreiner's specimen the splice plates are flush, top and bottom, with the main plates, while in the specimens in this investigation the base plate extends both above and below the limits of the cantilever.

Figure 5 is presented in an effort to make clear the extra duties demanded of the ends of the vertical welds. For more detailed discussion the reader is referred to the appendix; but briefly stated, the base plate is deformed in the region between $A$ and $B$ (likewise at the bottom). The weld at $B$ not only has to supply the force to strain the plate there but also has to supply the force to strain the base plate in the entire region between $A$ and $B$. Since, in Schreiner's specimens the plates connected by the welds are flush with each other there appears to be no good reason to take exception to his assumption of a straight line distribution of stress. In a practical application, therefore, it is necessary to judge which

**Table 1—Results of Tests**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Spec. No. | Cantilever Plate | Stress Relief | Moments, lb.-in. 1st Flaking | Final | Computed Max. Weld Stress S=6M/2d² (lb./in.) | S=4M/2d² |
| 1 | 5" × ½" | Yes | 132,000 | 192,000* | 23,000 | 15,400 |
| 2 | " | No | 160,960 | 201,360** | 24,200 | 16,100 |
| 3 | 5" × ¾" | No | 150,000 | 245,500*** | 29,400 | 23,500 |

* Downward deflection of end of cantilever, – 1½"
** Cantilever plate buckled sidewise. No evidence of weld failure in specimens 1 & 2
*** Weld failure. Plate deflection, – ½"

specimen, Schreiner's or the authors', that the joint in question more nearly simulates.

Table 1, which gives the results of the tests to destruction, overwhelmingly confirms the Schreiner theory. On specimens 1 and 2 the cantilever plates were but ½ inch thick. This thickness would have been sufficient to force fracture in the welds had a straight-line distribution of stress obtained. A half-inch fillet weld should have an ultimate value of 19,000 to 20,000 lb. per inch or better. In column 6 of Table 1 it is noted that the computed stresses (based on the flexure formula) are all too high. On the other hand, when Schreiner's advocated rectangular distribution of stress method is used, as shown in the last column, good values are obtained. It should be noted that in only the third specimen did the welds actually fail.

## CONCLUSIONS

The conclusion from this investigation is that apparently both Shedd and Schreiner are correct. The authors are of the opinion that the straight-line distribution of stress theory should continue to be used because it is so well known and is amply safe for static loads. But when joints are to be subjected to repeated loads, the straight line concept of stress distribution should be discarded or modified. The extent to which this concept might be modified was suggested in Shedd's discussion, namely, that the working stresses be halved. It should be noted that no fatigue tests were made in this investigation and that halving the working unit stresses is proposed not for all cases where joints are subjected to repetitive loadings but for those joints found in buildings and bridges and similar structures where the total number of repetitions up to full working stress probably will be but one or two hundred thousand times at most in the life of the structure.

## APPENDIX

As a common sense check on the measured strain distribution Fig. 5 is presented which endeavors to picture the deformation in the region of the joint. Line $X$–$X$ is the vertical edge of the unloaded base plate, and line $Y$–$Y$ represents a line on the unloaded weld near its intersection with the cantilever. Curved line $X'$–$X'$ represents the deformation which takes place in the base plate when the load is applied to the cantilever. Similarly, $Y'$–$Y'$ is the deformed position of line $Y$–$Y$. $Y''$–$Y''$ is parallel to $Y'$–$Y'$ but drawn through the center of line $X$–$X$. The deformation measured by the tensometers on the welds may be represented by the distance between $Y''$–$Y''$ and the curved line $X'$–$X'$. A little study will reveal that this deformation when drawn from a vertical base and to a larger scale would be much like curve $B$ in Fig. 4, thus giving credence to the findings in this investigation.

Another proof that an unfavorable distribution of stress in the welds is to be expected may be explained by the force arrows in Fig. 5. Due to the strain which takes place in the base plate in the region of $X'$, the resultant will be farther from the neutral axis than if the base plate did not extend above and below the cantilever as was the case in Schreiner's specimens (Fig. 2). The resultant for the forces in the welds must match the resultant for the base plate, and the inference is that there must be, therefore, a less favorable distribution in the welds than is given by the ordinary flexure formula.

# EFFECT OF RIGID BEAM-COLUMN Connections on Column Stresses*

By INGE LYSE† and E. H. MOUNT‡

## INTRODUCTION

A STUDY of the design and behavior of the top angle beam connection designed for end restraint appeared in the October 1936 and October 1937 issues of THE WELDING JOURNAL.[1] The present paper contains the results of a study of the localized column stresses produced by this type of connection. The investigation was sponsored by the Structural Steel Welding Committee of the AMERICAN WELDING SOCIETY and was carried out at the Fritz Engineering Laboratory of Lehigh University.

The column moments induced by partial rigidity in the beam connection may be determined by modification of any one of a number of methods of rigid frame analysis. This investigation was, therefore, confined to a study of those localized column stresses of a secondary nature. The object of the investigation was to determine whether these secondary stresses acting simultaneously with axial column loads were of sufficient magnitude to cause local buckling of the column when subjected to vertical loading.

A series of beam-column connections with column size, beam size and top-angle size as variables were investigated. Analysis of the data obtained indicates that these localized stresses are of a negligible order within the proposed limits of the top angle connection.

## ACKNOWLEDGMENT

The investigation was carried out under the direction of the Structural Steel Welding Committee of which Mr. L. S. Moisseiff is Chairman and Mr. W. Spraragen, the Secretary. Acknowledgment is due all members of the Committee for their interest in the work and their assistance in formulation of the test program. Acknowledgment is also due Mr. Roger Fluck of the Bethlehem Steel Company for welding of specimens and Mr. H. J. Godfrey and other members of the Fritz Engineering Laboratory staff for their assistance in carrying out this investigation.

## TEST PROGRAM

The original program provided that the principal testing be carried out using a simplified specimen consisting of a plate simulating the tension flange of a beam, welded to the column flange. Direct tension was applied to the plate which in turn transferred the tension to the column flange and web. Pilot tests, however, indicated that this type of specimen could not be made to duplicate column flange stresses produced by the welded top angle connection. The program was, therefore, revised and a cantilever specimen of the type shown in Fig. 1 was substituted. The program in its final form provided for the testing of fourteen specimens of this general type with beam size, column size, and top angle size varying as indicated in Table 1.

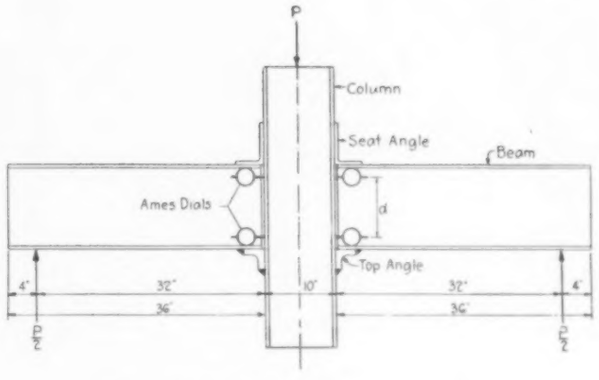



FIG. 1 - TYPE OF SPECIMEN USED IN INVESTIGATION

## FABRICATION OF TEST SPECIMENS

The stub columns were cut to size and mounted horizontally on a jig. The seat angle was then welded in place. The beam was set in place and shimmed to allow 1/8 to 1/4-inch clearance between beam end and column face. The beam was tack-welded to the seat angle and the shims removed. The top angle was tack-welded in place and the beam checked finally for perpendicularity to column face. The top angle welds were completed and the jig rotated through 90° to allow placing of the final seat angle welds in the horizontal position. The specimen was then reversed in the jig and the procedure repeated in attaching the second beam to the opposite column face. Top angle welds were placed in two ways. The weld-metal was placed in a series of beads until the desired weld size was reached, or the jig was rotated through 45° and the weld-metal deposited by a series of flat horizontal beads. No appreciable difference in behavior between welds made by these two methods was noted in testing and, therefore, no differentiation is made in the test data between specimens welded by the two methods.

All welds were made by a qualified welder and upon failure showed excellent fusion and absence of inclusions

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* Paper to be presented at Annual Meeting, A. W. S., Detroit, Mich., Oct. 16 to 21, 1938. Contribution to Structural Steel Welding Research Committee.

† Professor of Reinforced Concrete and Solid Bridges, Norway's Institute of Technology, Trondheim, Norway; formerly Research Professor of Engineering Materials, Lehigh University, Bethlehem, Pa.

‡ AMERICAN WELDING SOCIETY Research Fellow, Lehigh University, Bethlehem, Pennsylvania, in immediate charge of investigation.

[1] Progress Report on Welded Beam-Column Connections, by Inge Lyse and G. J. Gibson.

Effect of Welded Top Angles on Beam-Column Connections, by Inge Lyse and G. J. Gibson.

or blow-holes. All large welds were made with $^{3}/_{16}$-inch heavy mineral coated electrode and all tack-welds and small finishing beads were made with $^{5}/_{32}$-inch coated electrode.

## METHOD OF TESTING

All specimens were tested to failure in a 300,000-lb. Olsen testing machine. Loading was applied as shown in Fig. 1. The beams were supported on rollers placed 32 inches from the column faces and the load applied to the center of the column through a spherical bearing block.

The rotation of each beam at the face of the column was measured by means of four Ames dials reading to $^{1}/_{1000}$ inch attached to the beams with plungers bearing against the column face as shown in Fig. 1. Gage plates were tack-welded on the center line of the column web opposite both seat and top angles. Three rows of gage holes were spaced at varying distances from the column web. Corresponding gage holes on the inner surface of the column flange permitted measurement of column flange deflections relative to the column center line. Gage holes were spaced at 2-inch intervals in the rows and permitted observation of deflections four inches above and below the weld connecting top angle to column and two inches above and below the heel of the seat angle. An Ames dial reading to $^{1}/_{1000}$ inch and modified as shown in Fig. 2 was used in measuring the flange deflections.

The specimens were whitewashed before testing and observation of scaling aided in determining the location of critical points.

## TEST DATA

General information concerning specimen size, design loads, ultimate strength, apparent factors of safety and flange deflections is presented in Table 1. The factors of safety listed in Table 1 are factors of safety against end failure. It should be remembered that the flexibility of this type of connection is such that failure by overstressing at the center of the beam will occur prior to ultimate failure of the connection. The tabulated flange deflections are those observed at the flange edge at the point of attachment of the top angle and at the heel of the seat angle. Deflections of slightly greater magnitude than those recorded at the top angle were observed at a point on the flange edge two inches below the point of attachment of the top angle. This phenomenon was the result of the moment applied to the column flange by the top angle and disappeared as loads were increased above the design load, so that the maximum deflections occurred at the point of attachment of the top angle. The shift in the point of maximum deflection may be accounted

TABLE I

| Top Angle Size | Column Size | Beam Size | Top Angle Design Load | Observed Ultimate Load | Factor of Safety | $\Delta ta$* | $\Delta sa$** |
|---|---|---|---|---|---|---|---|
| inches | | | lb/in. | lb/in. | | in. | in. |
| 3 x 3 x 1/4 Length = 5 | B 10b 49 | 12I 31.8 | 280 | 1170 | 4.18 | 0.002 | 0.001 |
| 3 x 3 x 1/2 Length = 5 | B 10b 49 | 12I 31.8 | 1230 | 2590 | 2.10 | .002 | .001 |
| 3 x 3 x 5/8 Length = 5 | B 10b 49 | 12I 31.8 | 2055 | 4250 | 2.07 | .003 | .002 |
| 3 x 3 x 3/4 Length = 5 | B 10b 49 | 12I 31.8 | 3250 | 6240 | 1.92 | .005 | .011 |
| 3 x 3 x 1/2 Length = 10 | B 10b 49 | B 10b 49 | 1230 | 2990 | 2.43 | .010 | .005 |
| 3 x 3 x 1/2 Length = 8 | B 10b 49 | B 10b 49 | 1230 | 2880 | 2.34 | .006 | .006 |
| 3 x 3 x 1/2 Length = 6 | B 10b 49 | B 10b 49 | 1230 | 3280 | 2.66 | .003 | .005 |
| 3 x 3 x 1/2 Length= 5.5 | B 10b 49 | 15I 42.9 | 1230 | 2790 | 2.27 | .002 | .004 |
| 3 x 3 x 1/2 Length = 4 | B 10b 49 | 8I 18.4 | 1230 | 3000 | 2.44 | .004 | .000 |
| 3 x 3 x 1 Length = 10 | B 10b 49 | B 10b 49 | 7230 | 10140 | 1.40 | .043 | .027 |
| 3 x 3 x 3/4 Length = 10 | B 10b 49 | B 10b 49 | 3250 | 5450 | 1.68 | .017 | .015 |
| 3 x 3 x 3/4 Length = 8 | B 10 45 | B 10b 49 | 3250 | 6290 | 1.93 | .010 | .008 |
| 3 x 3 x 3/4 Length=5.75 | B 10 29 | B 10b 49 | 3250 | 9380 | 2.88 | .004 | .000 |

*$\Delta ta$ = Design load edge deflection of flange at point of attachment of top angle

**$\Delta sa$ = Design load edge deflection of flange at heel of seat angle

The 3 x 3 x 7/8 in. top angle failed in the fillet of the top angle as a result of a flaw in the steel. The data from this test therefore are omitted from the report.

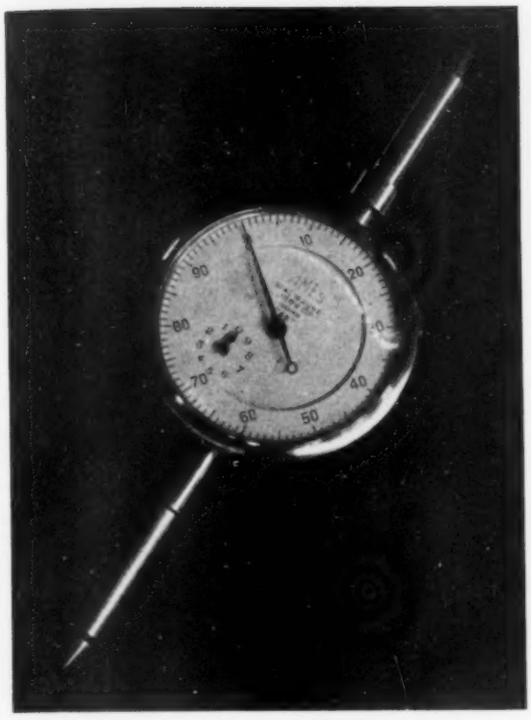


Fig. 2—Gage Used in Measuring Flange Deflections

for by the fact that yielding of the top angle weld at or slightly above design load allows the moment applied to the flange to increase at a much lower rate, while the direct pull continues to increase with the increased load.

Flange deflections observed for angles smaller than 3 by 3 by $^1/_2$ inch and having a length less than 8 inches were very small and erratic.

Typical transverse flange deflection curves for larger angles are shown in Figs. 3 and 4. In each case the left half of the figure shows the observed deflections at the point of attachment of the top angle and the right half of the figure shows corresponding curves for a point two inches below the top angle connection. Typical deflection curves of the flange edge are presented in Fig. 5. These curves show the local nature of the deflections. In all cases the plotted deflections are the average of observed deflections for corresponding points on opposite sides of the column web. The average was used in order to eliminate the effect of any eccentricity in the loading of the specimen.

Flange deflections at the seat angle were at all times small and erratic. The general trend, however, seemed to be in the direction of uniform deflection for all points on a transverse section which indicates that the major portion of the deflection was the result of elastic and plastic deformation of the web.

The measured end rotations of the beams were used in calculating heel deflections of the top angles and in the determination of the rigidity of the connection. A typical load-deflection curve is shown in Fig. 6. The results were plotted for three angles of the same size, 3 by 3 by $^1/_2$ inch but with varying lengths of 6, 8 and 10 inches. The fact that the points fall so closely together indicates that variation in length has no effect upon the flexibility of the connection. However, increase in the length of the angle over six inches showed a tendency to decrease the efficiency of the connection, i.e., decrease the ultimate load expressed in pounds per inch length of

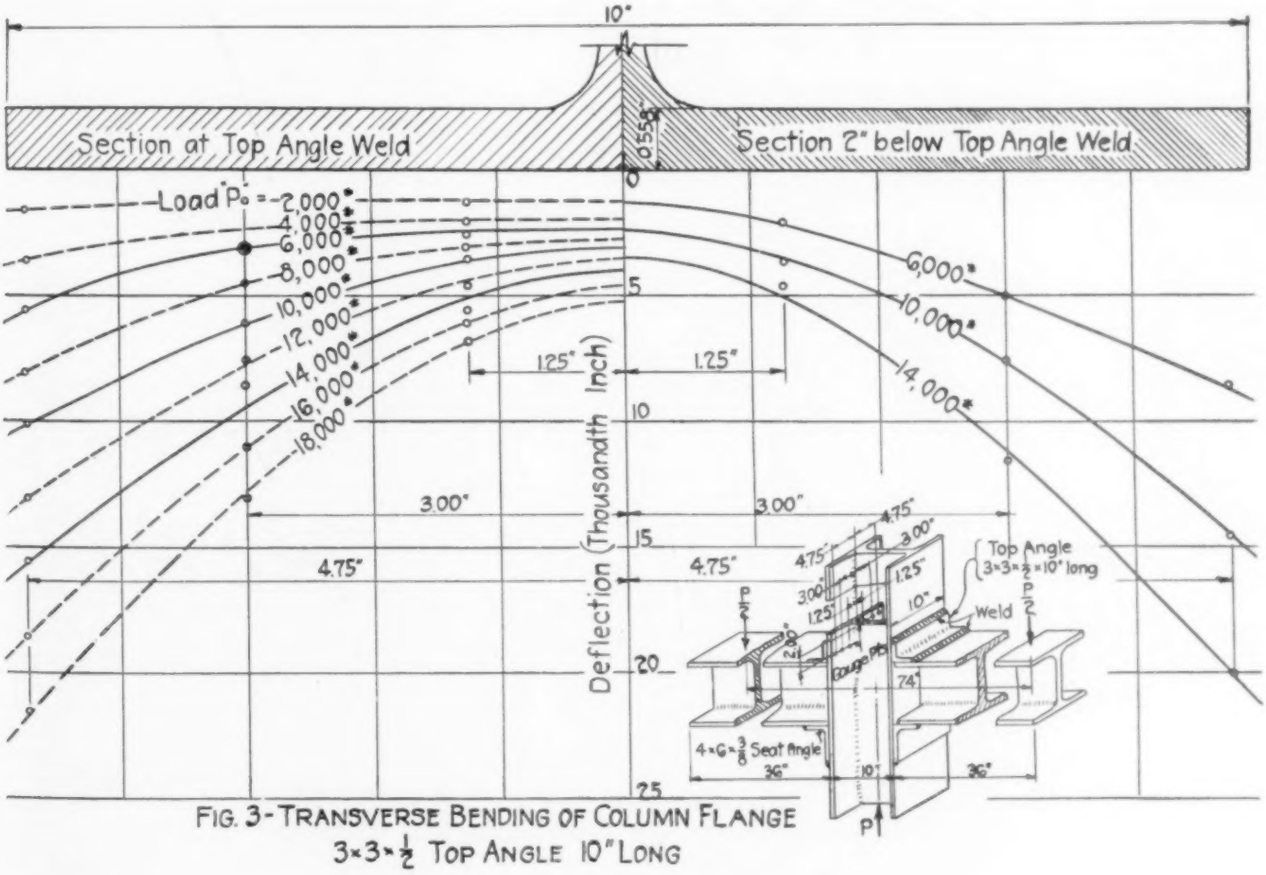



FIG. 3-TRANSVERSE BENDING OF COLUMN FLANGE
3×3×½ TOP ANGLE 10" LONG

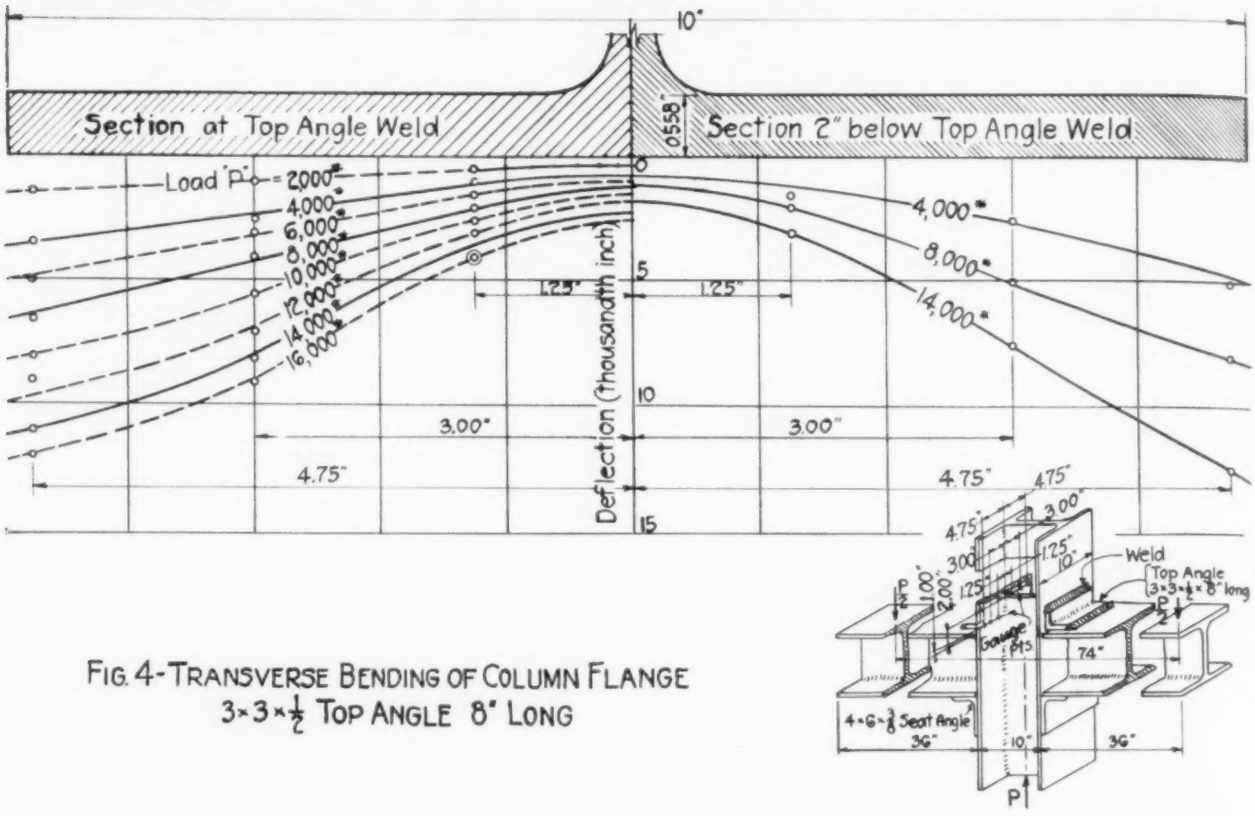



FIG. 4-TRANSVERSE BENDING OF COLUMN FLANGE
3×3×½ TOP ANGLE 8" LONG

top angle. This tendency became particularly pronounced in angles as large as 3 by 3 by $^{7}/_{8}$ inch and 3 by 3 by 1 inch. Figure 7 shows the type of failure which occurred in a 3 by 3 by 1 inch top angle 10 inches in length. This failure is typical of angles of this size.

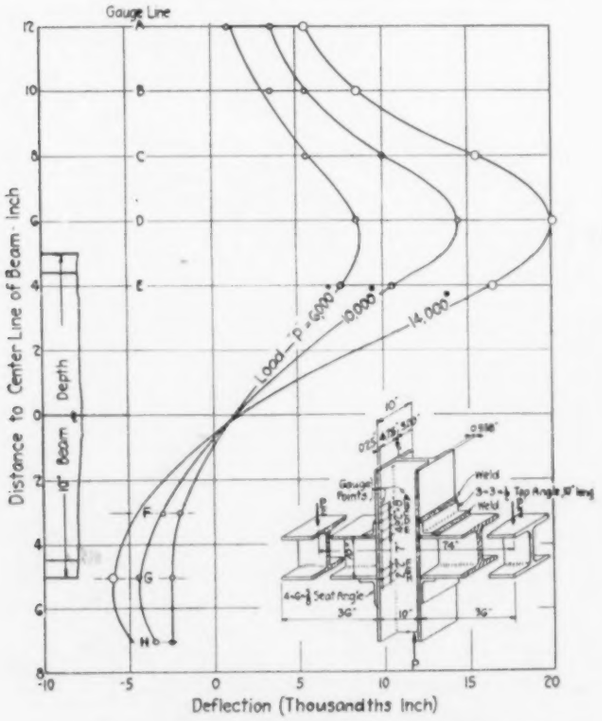



FIG 5- LONGITUDINAL BENDING OF COLUMN FLANGE
3×3×½ TOP ANGLE 10" LONG

Failure started by tearing of the weld at the root in the center of the column flange and progressed toward the throat and in both directions from the center to the ends of the welds.

Elastic and plastic deformations of the web contribute materially to the center deflections of the flange as shown in Figs. 3 and 4. The critical points are shown by the scaling of the whitewash in Fig. 8. The scaling at the top angle is inclined at 45° indicating that the principal force acting is direct tension applied at the point of attachment of the top angle to column flange and acting in a direction perpendicular to the column flange. The scaling at the seat angle is typical of web crippling due to bearing loads.

## DISCUSSION AND ANALYSIS OF TEST RESULTS

Before any attempt was made to analyze the column stresses it was necessary to establish an upper limit of top angle size which in turn established the maximum load which need be considered in the analysis of column stresses and deflections.

The rigidity of the cantilever connection was computed as shown in Fig. 9. The cantilever was assumed to be an end portion of a partially restrained beam having an identical connection at the opposite end, the point of inflection being coincident with the point of application of load to the cantilevered beam. The load, end rotations and point of inflection being fixed by test procedure and results, it was possible to calculate the length of this imaginary beam and to compare its free end rotation with the observed rotation of the cantilever. This comparison gave a measure of the rigidity developed by the connection under various load conditions. Figure 10 presents a comparison of rigidities developed by three sizes of angle, namely: 3 by 3 by $^{1}/_{2}$ inch; 3 by 3 by $^{5}/_{8}$ inch; and 3 by 3 by $^{3}/_{4}$ inch. The length of these angles was also a

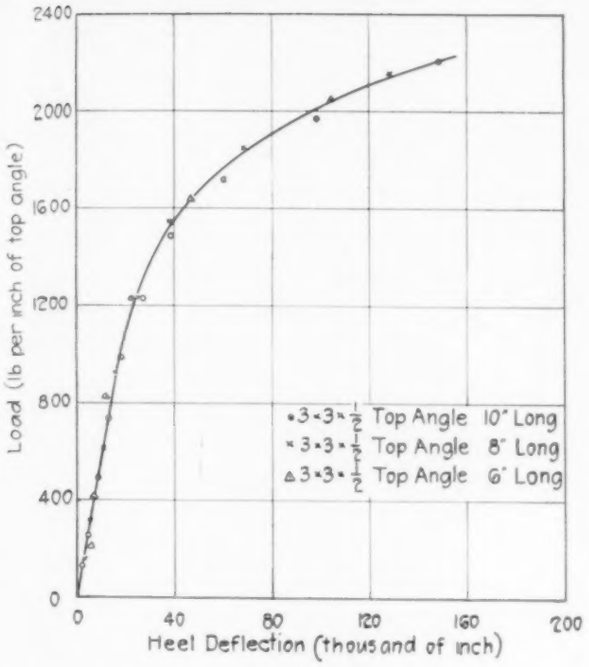
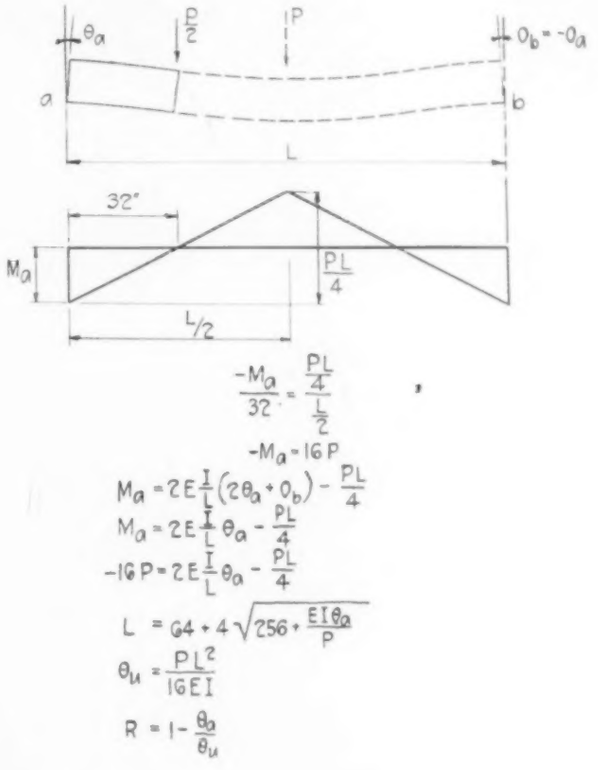



FIG. 6- LOAD DEFLECTION CURVE FOR TOP ANGLE

variable but Fig. 6 showed that the length has no effect upon the flexibility or its reciprocal, rigidity. In calculating the rigidity of the connection it was necessary to use a beam size which when coupled with the connection in question gave a balanced design. Since Table 1 shows that beam size has no effect upon the action of the top angle it was necessary to consider the balanced design only in computation of the rigidity. The dotted curve in Fig. 10 intersects the rigidity curves at the per cent fixity developed at design load. These curves are typical of others plotted for the remainder of the specimens. They show that in all cases the rigidity developed at design load is well above the minimum allowable rigidity of fifty per cent. They also show that design load rigidity tends to increase with angle size rather rapidly for those sizes equal to or greater than 3 by 3 by $^3/_4$ inch. This increase in rigidity is caused by two factors. First, general yielding throughout the entire weld is improbable in the larger size welds. Second, the ductility of the top angle transverse to the direction of rolling was found by free-bend tests to decrease rather markedly in angle sizes above 3 by 3 by $^3/_4$ inch. As the flexibility of the connection depends upon the yielding of the top angle weld and the ductility of the angle itself, these two factors tend to increase the rigidity as mentioned above. This increase in rigidity of the connection is accompanied by a comparable decrease in the factor of safety against end failure. The flexibility of the connection might be increased by increasing the length of leg of the top angle but this in turn decreases the allowable load on the connection. Therefore, an increase in the amount of material used in the connection at this point is not accompanied by a corresponding increase in load-carrying ability.




$$\frac{-M_a}{32} = \frac{\frac{PL}{4}}{\frac{L}{2}}$$

$$-M_a = 16P$$

$$M_a = 2E\frac{I}{L}(2\theta_a + \theta_b) - \frac{PL}{4}$$

$$M_a = 2E\frac{I}{L}\theta_a - \frac{PL}{4}$$

$$-16P = 2E\frac{I}{L}\theta_a - \frac{PL}{4}$$

$$L = 64 + 4\sqrt{256 + \frac{EI\theta_a}{P}}$$

$$\theta_u = \frac{PL^2}{16EI}$$

$$R = 1 - \frac{\theta_a}{\theta_u}$$

FIG. 9- METHOD OF CALCULATING RIGIDITY

The drop in efficiency of the connection accompanying the use of lengths over six inches in the larger angles is explained by consideration of the type of failure pictured in Fig. 7. It is evident that at loads near the ultimate all portions of the top angle weld are not contributing full value at the same time. This condition can occur only in extreme cases and is eliminated entirely if an upper limit to top angle size be set at a point such that the largest beam used in a balanced design would require a top angle of length not in excess of six inches. The above considerations led to the establishment of an upper limit to top angle size of 3 by 3 by $^7/_8$ inch.

Examination of the transverse deflection curves of Figs. 3 and 4 reveals the fact that the deflections may be separated into two parts, that due to bending of the flange

Fig. 7

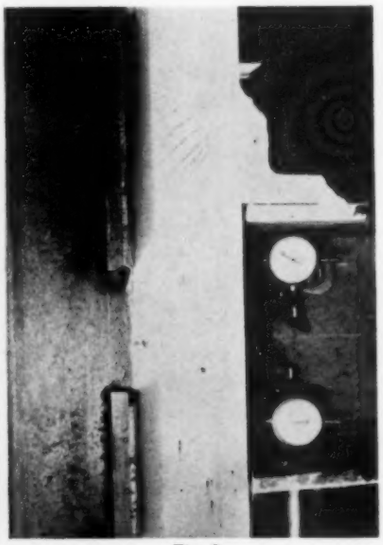


Fig. 8

Fig. 7—Failure of Large Size Top Angle Connection
Fig. 8—Web Yielding Indicated by Scaling of Whitewash

and that due to yielding of the web. Such a division can be only approximate as no actual measurements of web deformations were made.

Consideration of that portion of the deflection due to bending of the flange revealed that the transverse deflection curves were very similar to the deflection curves of a simple cantilever uniformly loaded. A method of analysis proposed in an article by Gregor, appearing in *Der Praktische Stahlhochbau*, Band IV, 1932, and reviewed in *La Soudre A L'Arc Electrique*, was used with certain modifications. A portion of the column flange was assumed to act as a cantilever with its fixed end at the column web and loaded uniformly with the design load of the top angle. The dimensions of the cantilever were assumed as follows: width equal to the width of column flange, and length equal to one-half the length of the column flange. Since the top angle contributes to the stiffness of the cantilever, the depth of the cantilever was taken equal to the thickness of the column flange plus three-eighths the thickness of the top angle. A comparison of computed and observed deflections is shown in Fig. 11.

Examination of rolling tolerances led to the establishment of a maximum allowable edge deflection of the flange relative to the center of the flange of 0.1 inch. Substituting this value together with the design load of the 3 by 3 by $^7/_8$-inch top angle in the standard deflection equation for the free end of a cantilever provides the worst possible case with regard to flange deflection. For the following rotations we have:

$\Delta$ = deflection in inches
$w$ = load in pounds per inch = 5100 in.-lb.
$l$ = length of cantilever = $\frac{1}{2}$ flange width = $\frac{F}{2}$
$I = \frac{1}{12} bd^3$
$b$ = flange width = $F$
$d$ = flange thickness + $\frac{3}{8}$ top angle thickness = $t + 0.328$

$$\Delta = \frac{l^4}{8\,EI}$$

$$0.1 = \frac{5100\left(\frac{F}{2}\right)^4}{8 \times 30{,}000{,}000 \times \frac{1}{12} F\,(t + 0.328)^3}$$

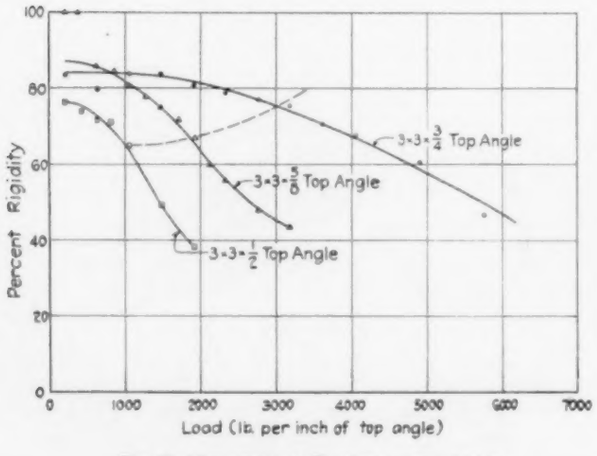



FIG. 10- VARIATION IN RIGIDITY WITH LOAD

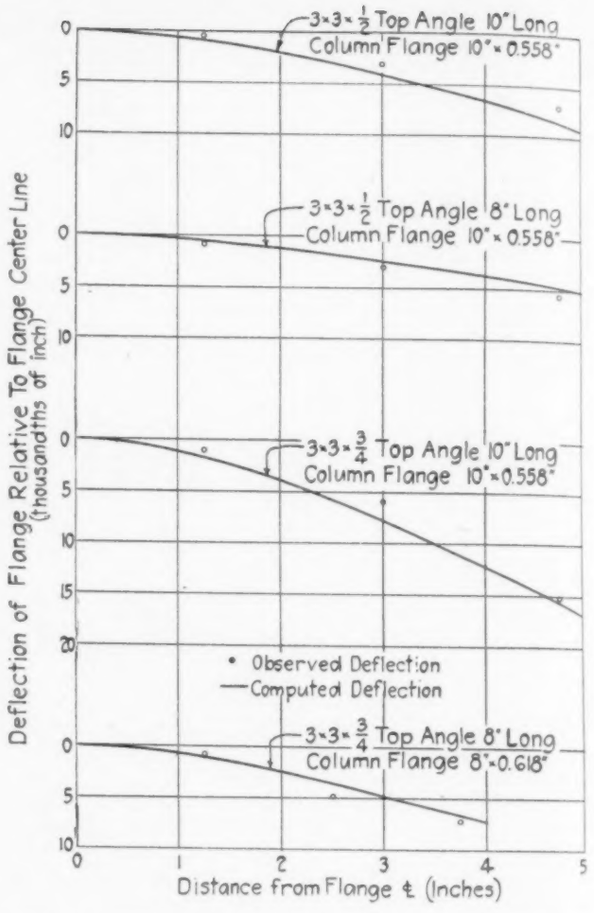

3×3×½ Top Angle 10" Long
Column Flange 10"×0.558"
3×3×½ Top Angle 8" Long
Column Flange 10"×0.558"
3×3×¾ Top Angle 10" Long
Column Flange 10"×0.558"
• Observed Deflection
—Computed Deflection
3×3×¾ Top Angle 8" Long
Column Flange 8"×0.618"
Deflection of Flange Relative To Flange Center Line (thousandths of inch)
Distance from Flange ℄ (Inches)

FIG. 11- COMPARISON OF OBSERVED AND COMPUTED FLANGE DEFLECTIONS

Solving this equation gives:

$$\frac{F}{t + 0.328} \leq 18.4$$ as the limiting ratio of flange

width to flange thickness. Examination of a standard table of $H$ and column sections shows that all are well within this limit. That portion of the flange deflection which was caused by bending is, therefore, negligible.

The portion of the deflection caused by yielding of the web was confined to safe limits by limiting the web stress at critical points. Observation of scaling of the whitewash showed that the seat angle at all times gave a better distribution of load over the column flange and web than the top angle. The critical point is, therefore, located at the point of attachment of the top angle. Limiting of web stress at this point should make the connection amply safe. Computation of the web stress was treated as a bearing problem with a tensile force substituted for the bearing load. The total top angle design load was considered to be distributed at 45° through the flange into the web giving a stressed area equal to the web thickness times the length of leg of top angle weld plus twice the flange thickness. For:

$t$ = flange thickness
$T$ = web thickness
$P$ = top angle load = pounds per inch of top angle times length of top angle
$f$ = length of leg of top angle weld
$F$ = flange width = top angle length,

we have:

$$\frac{P}{(f + 2t)T} = 24{,}000^{*} \text{ psi}$$

Substituting the load and dimensions of the 3 by 3 by $^{7}/_{8}$ inch top angle gives a limiting ratio of flange width to web thickness of:

$$\frac{F}{T} \leq 94.1\,(0.437 + t)$$

Examination of a large number of $H$ and column sections showed all to be well within this limit.

### SUMMARY AND CONCLUSIONS

1. The rigidity of welded top angle connections at design load increases with increase in angle thickness and is well above the minimum allowable end restraint of fifty per cent.

2. Practical consideration of economy, rigidity and safety limits the top angle size to a maximum of 3 by 3 by $^{7}/_{8}$ inch.

3. The flange deflections produced by the welded top angle connection may be separated into two parts, that due to flange bending and that due to web deformation. The bending deflections may be computed by assuming a portion of the flange to act as a simply uniformly loaded cantilever. The web deformations may be held within reasonable limits by analyzing the web stresses in a manner similar to bearing stress computations.

4. The localized stresses and deformations produced by the welded top angle connections are of a negligible order of magnitude providing the upper limit of top angle size is not exceeded. If further assurance of this fact is required, one need only consider the fact that the column is always laterally supported at the connection. Therefore, local stresses and deformations of the order produced by the connection cannot possibly cause column failure under primary loading.

* Allowable secondary stress.

# A QUICK SHOP TEST FOR QUALITY of Weld and Its Correlation with the Standard Tests*

By WILLIAM J. CONLEY†

SINCE the appearance of a fracture depends on the type of stress which caused the failure as influenced by the crystalline structure of the metal or alloy, a brief description of stress follows. Regardless of the kind of material or loading, there are only two stresses possible, namely, normal and tangential. The normal stress can be subdivided as tension and compression which are due to loads that tend to lengthen or shorten the loaded member in the direction of the load. Tangential or shear stress is produced when the load tends to slide the parts or portions of a member across each other. It is important to have these definitions in mind since all metals and alloys are crystalline in character having definite planes producing directional properties which cause them to react in a specific manner to a given type of stress.

In addition, these stresses are related as can be illustrated simply by Fig. 1. Figure 1 (*a*) shows a cylindrical piece in the grips of a testing machine subjected to an axial load tending to pull it apart lengthwise to produce tension in the section $A$–$B$. Figure 1 (*b*) shows the section $A$–$B$ with the tensile load $L$ represented diagrammatically. Suppose that the load is 10,000 lb. and that the diameter of the piece $A$–$B$ is 0.505 inches, the unit tensile stress produced at any point in a cross section such as 1–2 perpendicular to the direction of loading will be 10,000 lb. divided by 0.2 sq. in. or 50,000 lb. per sq. in. The tendency to pull the piece apart at the section 1–2 produces an internal stress, between the atoms of the metal or alloy, of 50,000 lb. per sq. in.

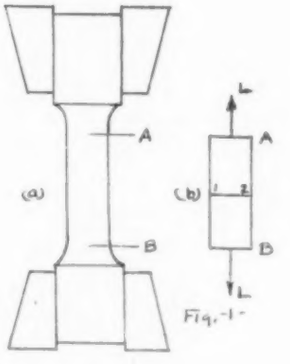


Fig. 1

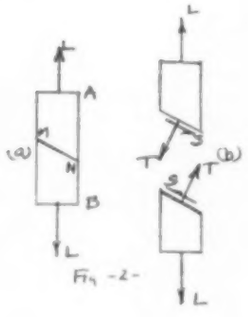


Fig. 2

Referring to Fig. 2 (*a*), the section $A$-$B$ is represented with an analysis plane $MN$ which is not perpendicular to the axis but at any angle with it. In Fig. 2 (*b*) the two sections on each side of $MN$ are imagined as separated, the internal reactions being designated as forces $T$ and $S$. $T$ is the total internal tension while $S$ is the total internal shear, which shows that although the part $A$–$B$ is loaded in tension, shear is present also. Mathematically it can be shown that the unit shear resulting from tension, called secondary shear, is a maximum in the direction at 45 degrees to the length of $A$–$B$ and equal to one-half the unit tensile stress. Thus, when a material is less than one-half as strong in shear as in tension it will start to

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† Professor Applied Mechanics, The University of Rochester.

fail in shear even though it is loaded in tension. This action produces the familiar cup-cone fracture of low-carbon or structural steel when loaded to failure by a tensile force. The first failure occurs at the outside and works in along the sides of the cup or cone in shear, the final break occurring in tension across the flat. A material which shows this type of fracture is called ductile.

For materials having varying ductility there is a relation between the length of the sides of the cup or cone and the area of the flat according to the relative values of these; the more shear area, the more ductile the metal. As the ductility decreases, therefore, the fracture approaches more and more a flat section perpendicular to the axis of the piece, until for a brittle alloy like cast-iron or hard steel the break is entirely flat. Unless the section *A–B* consists of material which is extremely brittle it will tend to draw out along the length and reduce locally to some extent before the final failure straight across, being known as semi-ductile. A ductile material always fails in shear at about 45 degrees to the direction of the tensile loading, while a brittle substance fails in tension across a section perpendicular to the direction of the maximum tensile stress. The appearance of the fracture is typical of the failure, a shear producing a non-crystalline or silky effect, while the tension shows spots of reflected light, the number being inversely proportional to the grain size or crystal size. Conversely, when a material is loaded in shear, there are secondary tensile and compressive stresses. However, in this case the intensity of these stresses is equal to the shear in planes at 45 degrees to the direction of the primary shear. Thus, a brittle material which is weaker in tension than in shear will fail by tension when loaded in shear. With this brief description in mind it can be seen that much can be told about the quality of a metal or alloy by observing the fracture. In addition, the broken section will reveal internal defects, such as gas holes, included slag, lack of fusion and internal stress conditions resulting from overstressing or heat treatment.

These facts have led the author to think critically about the standard tests so that during twenty years of experience the belief has grown that a simple nick-break test which can be performed in a few minutes by any one equipped with a hack-saw, hammer and vice will give much reliable information about the quality of a weld.

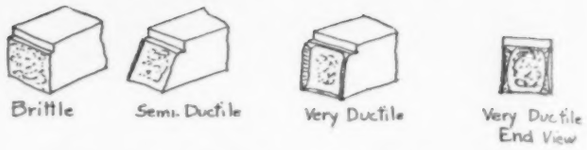


Fig. 3—Sketches of Different Types of Notched Impact Fracture

In other words, a crude impact test of the Izod type is made on the weld-metal. When the details of this break are studied it will be noticed that a piece which fractures easily and suddenly gives a flat coarsely crystalline surface indicating brittleness and low tensile strength. One which breaks suddenly requiring greater force will have a less coarse appearance with less brittleness. The failure of a ductile specimen will show a reduced cross section with silky sloping sides leading to the flat portion and the blow required to produce rupture will be noticeably greater. Of course, if the fracture is made in the weld material, as it can be, by locating the saw cut at that point, all the internal defects which may be present will be shown. Figure 3 attempts to depict fractures representing the conditions described above.

To check these conclusions, steel plates 5 inches by 12 inches were cut from the same $^3/_8$ inch thick strip of structural stock. Pairs of these were then welded, to

**Table 2**

| No. of Specimen | Maximum Tensile Stress Lb. per Sq. In. | Free-Bend Ductility | Izod Impact Ft.-Lb. | Rank from Fracture |
|---|---|---|---|---|
| 1 | 57,000 | 8 | 20 | 8 |
| 2 | 54,000 | 20 | 13 | 9 |
| 3 | 42,000 | 1 | 3.5 | 12 |
| 4 | 59,000 | 5.5 | 12 | 5 |
| 5 | 68,000 | 21 | 44 | 3 |
| 6 | 73,000 | 6 | 33 | 6 |
| 7 | 27,000 | 0 | 10 | 14 |
| 8 | 58,000 | 4.5 | 3.5 | 10 |
| 9 | 55,000 | 4 | 3.5 | 11 |
| 10 | 53,000 | 5 | 11 | 13 |
| 11 | 62,000 | 22 | 47 | 2 |
| 12 | 61,700 | 9 | 43 | 4 |
| 13 | 51,400 | 41 | 30 | 7 |
| 14 | 62,000 | 23 | 59 | 1 |
| 15 | 67,300 | 28 | 75 | |

**Table 1—Welding Procedure**

| Weld Number | Plate Material | Type of Weld | Amperes | Rod Description Make | No. | Size | Coated | Scarfed | Number of Beads |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Structural steel | D.C. | 200 | A | 7 | .... | Yes | Both sides | One |
| 2 | Structural steel | D.C. | 200 | A | 7 | .... | Yes | Both sides | One |
| 3 | Structural steel | D.C. | 200 | A | 7 | .... | Yes | One side | ..... |
| 4 | Structural steel and 18–8 | D.C. | 200 | A | 7 | .... | Yes | Both sides | Two and one |
| 5 | Structural steel and 18–8 | D.C. | 300 | 18–8 | .. | .... | No | Both sides | One |
| 6 | Structural steel | D.C. | 260 | A | .. | $^5/_{16}$ in. | Yes | Both sides | One |
| 7 | Structural steel | Oxy. | ... | Swedish iron | .. | .... | ... | Both sides | One |
| 8 | Structural steel | A.C. | 160 | B | 65 | $^5/_{32}$ in. | Yes | Both sides | One |
| 9 | Structural steel | D.C. | ... | B | 65 | $^5/_{32}$ in. | Yes | Both sides | One |
| 10 | Structural steel | Oxy. | No. 5 tip | Low carbon | .. | $^3/_{16}$ in. | No | Both sides | One |
| 11 | Structural steel | D.C. | 200 | C | .. | .... | ... | One side | Three and one |
| 12 | Structural steel | D.C. | 200 | A | 85 | $^5/_{32}$ in. | Yes | One side | Three and one |
| 13 | Structural steel | Reversed polarity D.C. | 250 | A | 5 | $^5/_{32}$ in. | Yes | Both sides | One |
| 14 | Structural steel | D.C. | 120 | A | 5 | $^5/_{32}$ in. | Yes | One side | Four |
| | | | 120 | | 7 | $^1/_8$ in. | | | Two |
| | | | 140 | | 7 | $^5/_{32}$ in. | | | One |
| 15 | Structural steel | D.C. | 250 | A | 7 | $^3/_{16}$ in. | Yes | U | ..... |

Number 13 was stress relieved. Number 15 was normalized, heated, quenched and drawn.

**Table 3**

| Test and Letter | | Rank of Specimens from Tests 5 | 6 | 1 | 2 | 4 | 10 | 7 | 8 | 9 | 3 | Rank-Difference Correlation | in Per Cent |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W | Izod | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 9 | 9 | 9 | W-X | 73 |
| X | Fracture* | 1 | 3 | 4 | 5 | 2 | 9 | 10 | 6 | 7 | 8 | W-Y | 60 |
| Y | Tensile | 2 | 1 | 5 | 7 | 3 | 8 | 10 | 4 | 6 | 9 | W-Z | 87 |
| Z | Bend | 1 | 4 | 3 | 2 | 5 | 6 | 10 | 7 | 8 | 9 | X-Y | 89 |
| | | | | | | | | | | | | X-Z | 81 |
| | | | | | | | | | | | | Y-Z | 64 |

* Shop Test.

Rank-Difference $= \left[1 - \frac{6\Sigma D^2}{N(N^2-1)}\right]$ times 100 for per cent.

produce a plate 10 inches by 12 inches, at several Rochester plants. The welding procedure for each set is shown in Table 1. The first series tested consisted of ten plates numbered from 1 to 10. These plates were machined to produce five each of the following test specimens; tension, bend and Izod impact, the Izod notches being located to cause failure in the weld-metal. Table 2 shows the averages of these test results.

Next typical Izod fractures of the weld-metal for each plate were arranged according to the quality as estimated by visual examination without reference to the physical test results. The specimens were then given numbers with 1 designating the piece judged to be of best quality and 10 that having the poorest properties. In judging the fractures, consideration was given to the amount of reduction of the section, the relative amount of shear area, the crystalline appearance, presence of slag, gas holes and lack of fusion. These results were plotted on the sheet with the tensile and Izod values giving the chart shown as Plate 1. The agreement between the form of these curves seemed to be so marked that it was decided to make another experiment on five welds prepared in the same manner with the welding procedure unknown to the author. Test specimens were prepared as in the case of the ten plates and in addition nick-break and a small section for the hammer or quick shop test were included.

This series of five was tested as a part of a lecture course given to the Rochester Section of the AMERICAN WELDING SOCIETY. The shop test specimens were broken first and the welds rated by means of the fractures. Then the standard tests were made with the results shown in Table 2 opposite numbers 11 through 15. A superficial examination of these data would seem to indicate that the correlation between the various tests was not good. In order to show this definitely a statistical analysis was made of the group of five using the rank-difference method of correlation by means of the formula, $R = 1 - (6 \times \Sigma D^2)/N(N^2 - 1)$ where $R$ is the correlation factor, $D$ the rank-difference, $\Sigma D^2$ being the summation of the $D^2$ terms and $N$ the number of items correlated. The results shown in Table 4 were disappointing for the five welds 11 through 15, but number 15 was

**Table 4**

| Test and Letter | | Rank from Tests 15 | 14 | 11 | 12 | 13 | Rank-Difference Correlation | in Per Cent | | |
|---|---|---|---|---|---|---|---|---|---|---|
| A | Izod | 1 | 2 | 3 | 4 | 5 | A-B | 10 | C-D | −60 |
| B | Fracture* | 4 | 2 | 3 | 1 | 5 | A-C | 40 | C-E | −10 |
| C | Nick-Break | 4 | 1 | 2 | 3 | 5 | A-D | 0 | C-F | 30 |
| D | Bend | 2 | 3 | 4 | 5 | 1 | A-E | −70 | C-G | 60 |
| E | Ductility | 5 | 3 | 2 | 4 | 1 | A-F | 90 | D-E | 30 |
| F | Tensile | 1 | 3 | 2 | 4 | 5 | A-G | 80 | D-F | −10 |
| G | Reduced Ten. | 2 | 1 | 4 | 3 | 5 | B-C | 70 | D-G | −20 |
| | | | | | | | B-D | −90 | E-F | −60 |
| | | | | | | | B-E | −40 | E-G | −70 |
| | | | | | | | B-F | 0 | F-G | 50 |
| | | | | | | | B-G | 50 | | |

* Quick Shop Test.

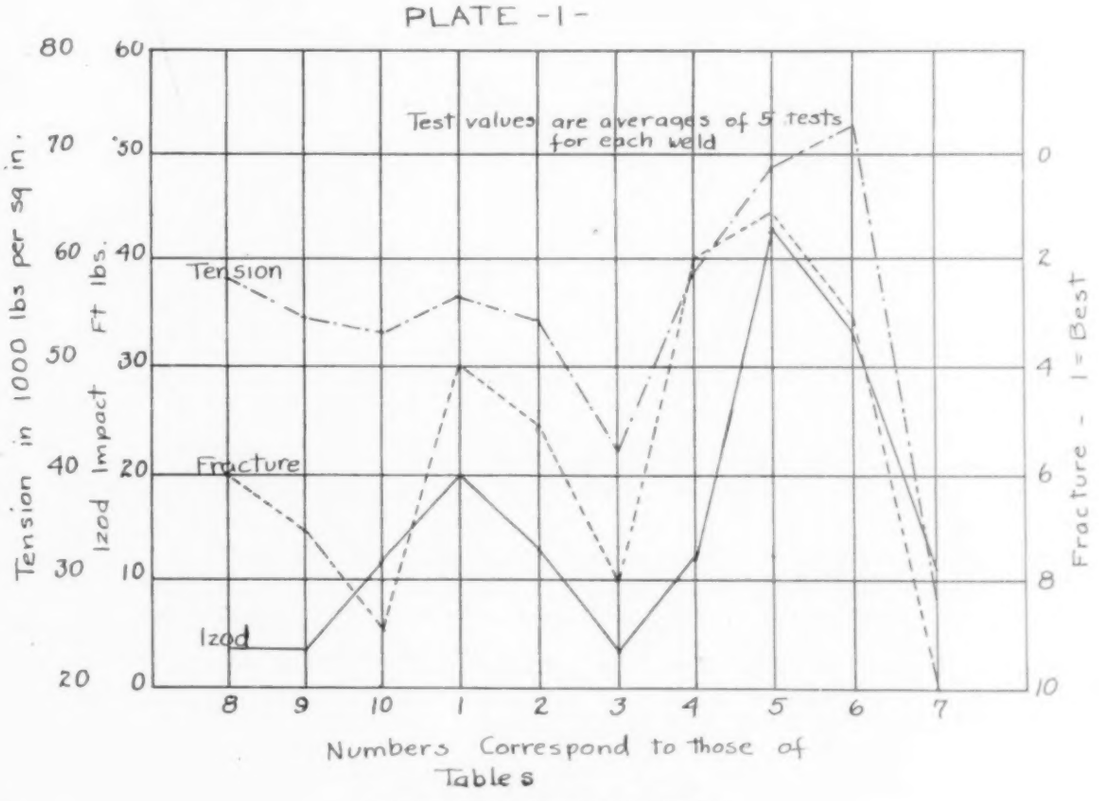
PLATE -1-
Test values are averages of 5 tests for each weld
Tension
Fracture
Izod
Tension in 1000 lbs per sq in.
Izod Impact Ft lbs.
Fracture - 1 = Best
80 60 70 50 60 40 50 30 40 20 30 10 20 0
0 2 4 6 8 10
8 9 10 1 2 3 4 5 6 7
Numbers Correspond to those of Table 5

a freak weld heat treated in addition. Number 15 was made by a special procedure at the request of the author so as to be sure to have one weld showing internal defects. To do this a single bead was laid down in the regular manner followed by another laid down relatively cold, the weld then being completed in the standard manner. However, this weld was normalized, heated, quenched and then drawn, producing a distinctly freak case. Thus, the heat treatment raised the strength of the sound part of the weld to allow it to perform well in spite of the considerable portion of poor bead making up the weld section. However, in the shop test the flaw showed to the eye and thus was responsible for the low rating of this weld. Leaving this specimen out of the analysis a very satisfactory correlation was obtained for the other four pieces as shown in Table 5.

**Table 5**

| Test and Letter | | Rank from Tests 14 | 11 | 12 | 13 | Rank-Difference Correlation in Per Cent | | | |
|---|---|---|---|---|---|---|---|---|---|
| A | Izod | 1 | 2 | 3 | 4 | A-B | 80 | C-D | −20 |
| B | Fracture* | 1 | 3 | 2 | 4 | A-C | 100 | C-E | −40 |
| C | Nick-Break | 1 | 2 | 3 | 4 | A-D | −20 | C-F | 80 |
| D | Bend | 2 | 3 | 4 | 1 | A-E | −60 | C-G | 80 |
| E | Ductility | 3 | 2 | 4 | 1 | A-F | 80 | D-E | 80 |
| F | Tensile | 2 | 1 | 3 | 4 | A-G | 80 | D-F | −40 |
| G | Reduced Ten. | 1 | 3 | 2 | 4 | B-C | 80 | D-G | −40 |
| | | | | | | B-D | −40 | E-F | −20 |
| | | | | | | B-E | −80 | E-G | −80 |
| | | | | | | B-F | 40 | F-G | 40 |
| | | | | | | B-G | 100 | | |

* Quick Shop Test.

Tables 3 and 6 show the results of the statistical analysis for the first group of ten welds and in turn for the combined list of the first ten and numbers 11 through 14. Since the Izod impact test is a refined nick-break method, this was used as the criterion for each series. Table 7 gives a summary of the different correlations in percentages.

**Table 6**

| Test and Letter | | Rank of Specimens from Tests 14 | 11 | 5 | 12 | 6 | 13 | 1 | 2 | 4 | 10 | 7 | 8 | 9 | 3 | Rank-Difference Correlation Per Cent | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W | Izod | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 12 | 12 | W-X | 91 |
| X | Fracture* | 1 | 2 | 3 | 4 | 6 | 7 | 8 | 9 | 5 | 13 | 14 | 10 | 11 | 12 | W-Y | 73 |
| Y | Tensile | 3½ | 3½ | 2 | 5 | 1 | 12 | 8 | 10 | 6 | 11 | 14 | 7 | 9 | 13 | W-Z | 86 |
| Z | Bend | 2 | 3 | 4 | 6 | 8 | 1 | 7 | 5 | 9 | 10 | 14 | 11 | 12 | 13 | X-Y | 84 |
| | | | | | | | | | | | | | | | | X-Z | 78 |
| | | | | | | | | | | | | | | | | Y-Z | 47 |

* Quick Shop Test.

**Table 7—Rank-Difference Correlation Per Cent**

| Tests Correlated | Number of Cases 10 | 5 | 4 | 14 |
|---|---|---|---|---|
| Izod-Fracture | 73 | 10 | 80 | 91 |
| Izod-Tensile | 60 | 90 | 80 | 73 |
| Izod-Bend | 87 | 0 | −20 | 86 |
| Izod-Nick-Break | | 40 | 100 | |
| Fracture-Tensile | 89 | 0 | 40 | 84 |
| Fracture-Bend | 81 | −90 | −40 | 78 |
| Fracture-Nick-Break | | 70 | 80 | |
| Tensile-Bend | 64 | −10 | −40 | 47 |
| Tensile-Nick-Break | | 30 | 80 | |
| Bend-Nick-Break | | −60 | −20 | |

For the most reliable results at least twenty pieces should have been used when applying the rank-difference method of correlation. It is appreciated that experiments of this kind are expensive both as to actual cost and time consumed so it is felt by the author that this set of fourteen is sufficient for the present purpose. Referring to Table 7, the Izod shop test, designated as the fracture method, gave a correlation of 10 per cent for the five welds which included the unusual piece, 80 for the four regular cases, 73 for the first series of 10 and 91 for the combined list of 14. The Izod-tensile values were 90, 80, 60 and 73 showing that the Izod impact gives good correlation with the tensile. For the fourteen pieces the shop-tensile results were 84 per cent, giving mathematical proof that the quick shop test is reliable for all practical purposes. Since the rating of the set of ten samples was the first attempt on the part of the author, it seems that extensive experience is not necessary to obtain satisfactory results. A series of fractures can be prepared for the individual shop to be rated and used as a set of standards by means of which a person with relatively little experience could successfully rate the welds. This quick method offers a reliable check which can be made inexpensively in any shop or on any job. It has the added advantage of allowing the welder to observe fractures of his welds so that he has a criterion by which to judge his technique for improvement of his work.

The author expresses his appreciation of the cooperation of many Rochester plants and individuals who aided in obtaining and machining the welds, especially Eastman Kodak Co., American Laundry Machinery Co., Ritter Dental, Dolomite Marine and the Metal Welders. Many thanks are due Mr. Pearse, instructor in Shop at the University of Rochester, and to Mr. Millard a graduate student who made many of the standard tests.


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# WELDING ARCS FROM THE Standpoint of Recent Investigations*

By C. G. SUITS†

SO much new knowledge about arcs has been gained in very recent years that it may be of value to bring some of this work to the attention of the AMERICAN WELDING SOCIETY in the hope that it may serve as a basis for more investigation along the line of the purely electrical and thermal aspects of the welding arc. It is a deplorable fact that the welding literature shows that little work is being done in this field which must be reckoned as of fundamental importance to the art. The very elementary state of popular knowledge of the arc is well brought out by two papers which recently appeared in a widely read welding journal, the information for which was up-to-date not later than the year 1923, and much of which was current knowledge before 1900.

Recent investigations have shown not only many new facts about arcs, and especially about welding arcs, such as a knowledge of the temperature of the arc gas, but they have served also to define the boundaries between fact and conjecture, so that much information which was formerly regarded as factual must now be designated with a question mark. For example, we have no direct means of measuring space potential and hence anode and cathode drops separately in any arc at atmospheric pressure, and our only knowledge of these quantities comes by inference from studies of low-pressure discharges.

Modern progress in this field started with the work of Compton in 1923, who laid the foundation for what was later to become the thermal theory of the arc. Compton[1,2] proposed that a process of thermal ionization developed earlier by Saha[3] could provide the quantitative basis for the fundamental process of current conduction in the arc. Briefly this theory treats the ionization reaction like a high temperature thermal equilibrium in which the components are, on one side of the equation, the neutral gas molecules, and, on the other side, the reaction products, which are the dissociated gas, the positive ions and electrons. Such reactions as reversible chemical processes have been much studied and are generally well understood. In the arc the heat of ionization becomes analogous to the heat of the chemical reaction and together with the temperature characterizes the equilibrium degree of reaction. Saha found that this thermodynamical treatment of ionization gave a quantitative explanation of many of the characteristics of stellar spectra. The first quantitative use of the theory was made by Langmuir and Kingdon,[4] who found that the ionization of caesium vapor on tungsten filaments could be treated by this equation. The application of this theory to arcs was a bold step, because it was entirely alien to the conduction mechanism which had become familiar from a study of low-pressure discharges. One fundamental property of the low-pressure discharge is the absence of a thermal equilibrium. In well known cases the electrons in the discharge may have a true temperature of the order of 30,000° in the presence of neutral gas at room temperatures. The absence of an adequate mechanism for the transference of energy from the electrons, which are accelerated by the electric field, to the neutral gas is accountable for this condition. On the other hand, the fundamental underlying a thermal ionization process is the concept of the thermal equilibrium in which all components of the discharge have a true temperature which is the same temperature. Direct evidence bearing on this point was not available at the time of Compton's work, but much later investigation has served to establish the thermal equilibrium as an essential characteristic of the high-pressure discharge. The most direct evidence on the question of thermal equilibrium comes from the work of Ornstein and his students,[5a,b,c] who have for this purpose studied the arc spectra. Their method is to measure the relative intensities in the spectral series and to calculate from known atomic constants what relative intensities would be expected if the energy levels corresponding to the observed lines were excited in a process of thermal equilibrium. In the case of a great many arcs studied in this way their results show that within the errors of measurement a thermal equilibrium exists throughout the energy levels in question. It may be argued that the equilibrium only exists for the particular energy levels in question, but when it is considered that this equilibrium excitation is found not only for the lines of a band but also in the band heads in a sequence and the electronic lines (in the Balmer spectrum of hydrogen), this argument loses much weight. Further evidence on the question of thermal equilibrium is found in the work of Mannkopff[6] and Witte,[7] which will not be discussed in detail. The idea of a thermal equilibrium underlies much later arc investigation and has provided a sound foundation for the application of the thermal ionization equation.

In view of this work it is surprising to find in the welding journal above mentioned the following statement: "(in the arc) All modern knowledge shows that ordinary concepts of 'temperature' are here quite meaningless." It would be more accurate to say that in few physical phenomena is the concept of temperature so well illustrated.

## THERMAL CONCEPTS IN THE ARC

At the time of Compton's work arc temperatures had not been measured, but many researches since then have given reliable values for the temperature in the core of the arc. These values lie between 4000° K. and 7000° K., and are a good deal higher than the speculative values that are found in the older literature. These tempera-

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ture measurements have been made by a variety of new methods, such as the spectrographic method of Ornstein[5a,b,c] the gas density method of von Engel and Steenbeck,[8] and Ramsauer,[9] the mercury arc method of Elenbaas,[10] and the velocity of sound method.[11a,b,c] The velocity of sound method is the only one of the available means which has the characteristics that allow its use with an unstable phenomenon like the welding arc. By this means gas temperatures have been measured in welding arcs under practical operating conditions, and a value of 6000° K. is found in two significant cases. In view of these many arc temperature researches which yield concordant results, it is regrettable that a modern review of the subject should state: "As a very rough approximation, however, we can say that the average 'temperature' in a welding arc is equivalent to about 2000–3000° C. on the ordinary temperature scales."

From the arc temperature measurements and the simultaneously obtained electrical measurements it is possible to determine whether the thermal ionization equation of Saha

$$\log_{10}\left(\frac{n^2}{N}\right) = -\frac{5040\ Ve}{T} + 1.5\log_{10}T + 15.38 \qquad (1)$$

(where $n$ is the electron density, $T$ the temperature, $N$ is the molecular density, and $Ve$ is defined below) can be applied quantitatively to the column of the high pressure arc. This has been done for low current arcs in air[11c] with interesting results. The quantity $Ve$ can be experimentally determined in this way. If the measurements were made in an idealized gas with a single critical potential, an ionization potential $V$, this quantity would be unquestionably the proper value to use in equation (1). In an arc in air, however, and particularly in a welding arc, there are ionization potentials $V$ distributed throughout the range between 4.33 volts and 15.80 volts, as shown by Table 1. What value to use for $Ve$ is therefore not obvious. The measurements in low current arcs in air, particularly between carbon electrodes, show that the $Ve$ is approximately 15 volts, which means that the arcs are practically free of metal vapor. When the arc atmosphere contains a partial pressure of metal vapor, $Ve$ will be lower than 15 volts. When the $Ve$ is known, the arc temperature $T$ can be calculated, or, conversely, when $T$ is known, $Ve$ can be obtained.

**Table 1**

| | Ionization Potential (Volts) |
|---|---|
| $N_2$ | 15.8 |
| N | 14.5 |
| $O_2$ | 12.5 |
| O | 13.6 |
| C | 11.22 |
| Fe | 7.83 |
| Mn | 7.40 |
| Ni | 7.64 |
| Co | 7.81 |
| Cr | 6.74 |
| Al | 5.95 |
| Na | 5.11 |
| K | 4.33 |

We may now apply the method to welding arcs for this latter purpose. The quantity $n^2/N$ can be calculated from the conduction equation $I = nekE$ with the result

$$\left(\frac{n^2}{N}\right) = A\left(\frac{I}{E}\right)^2 \qquad (2)$$

where $I$ is the current density (amps. cm.$^{-2}$) and $E$ the electric gradient (volts cm.$^{-1}$), and $A$ has the value $2.73 \times 10^{10}$ in air or nitrogen. Measurements of $E$ were made for the case of a heavily coated electrode ($W20$) and a bare electrode (type $L$) with the result

$$E_{W20} = 13.5\ (v\ \text{cm.}^{-1})$$

$$E_L = 31\ (v\ \text{cm.}^{-1}).$$

Current density $I$ was obtained by the measurement of arc diameter $D$ from high speed motion pictures as

$$I = \frac{i}{0.78\ D^2}$$

with the result that

$$I_{W20} = 480\ (A\ \text{cm.}^{-2})$$

$$I_L = 890\ (A\ \text{cm.}^{-2}).$$

From these values and for sound velocity temperature measurements of $T = 6000°$ K., we find

$$V_{W20} = 8.8 \text{ volts}$$

$$V_L = 9.0 \text{ volts},$$

which can be compared to the ionization potential of iron of 7.83 volts. We may conclude from this that whereas the low current arcs in air between refractory electrodes are substantially free of metal vapor and depend upon the ionization of $N_2$ and $O_2$ for conduction electrons, the welding arc is a metal vapor discharge with $Ve$ but slightly higher than that of iron itself. It is interesting to calculate what arc temperature would be required to account for the observed current density and gradient in an arc in air, were it free from metal vapor. By using $E$ and $I$ above, we find in this way $T = 9500°$ K., which can be compared to the measured temperature of 6000° K.

## GRADIENTS AND POTENTIAL DISTRIBUTION

It would be very useful to have available potential distribution data for welding arcs in a variety of experimental conditions, and this fact has been apparent to a great many workers.

For the purpose of obtaining analogous data in the low pressure discharge the probe method of Langmuir has been of the greatest value. Many investigators[12a,b, 13a,b,14] have applied the method and the interpretation of Langmuir to the arc at atmospheric pressure. Unfortunately the results obtained at high pressure are all subject to serious fundamental errors which arise from the fact that at high pressure the conduction to the probe takes place through an electrical sheath and a relatively large thermal sheath. Under these conditions there is no way of determining at present the space potential or electron temperature from electrical measurements on the probe. This has been realized by physicists for some time and was thoroughly investigated by Mason,[15a,b] whose conclusion is, "The probe measurements of previous investigators of high-pressure arcs must be considered as of little value." In spite of this fact, probe measurements on the high-pressure arc continue to appear in the literature.[16a,b]

This criticism should not be construed to be a discouragement of further investigations of possible means of interpreting high-pressure probe measurements, since a satisfactory treatment is to be hoped for as an ultimate development. But the errors of a literal interpretation

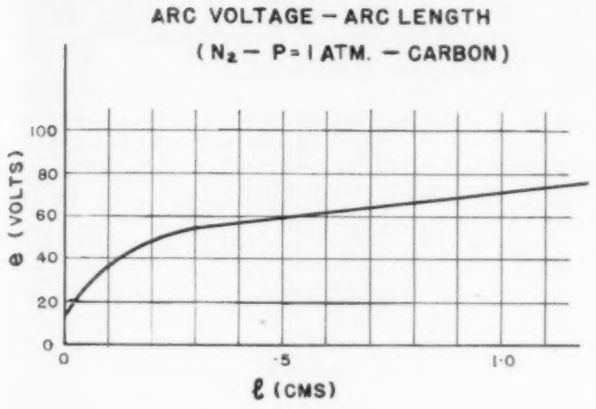


Fig. 1

of the high-pressure measurement should be evident from Mason's investigation. The error in estimating the space potential from the probe characteristic is estimated to be of the order of 8 volts. This is not serious in the high-voltage arc in a circuit breaker, but in the low-voltage welding arc the uncertainty of measurement becomes greater than the quantity being measured.

Although probe measurements of potential distribution and electron temperature cannot be interpreted at present, the determination of electric gradient can be made without difficulty. A comprehensive set of such measurements for a range of experimental conditions in the welding arc is much to be desired.

## ANODE, CATHODE AND POSITIVE COLUMN

If a potential distribution curve were available for the high-pressure arc, it might show, as at low pressure, a steep gradient near each electrode and a region of low gradient of constant magnitude in the interelectrode space. That this region of constant gradient exists is shown from a plot of total arc voltage $e$ as a function of arc length, as given by Fig. 1. In this region of constant gradient, $E = de/dl$, the space charge is zero, by Poisson's equation, and we have a positive column analogous in this respect to the low-pressure arc.

When the $e$-$l$ curve is traced out for short arcs, it is found that for lengths less than 3 mm. $E$ becomes greater with decreasing length until, just prior to short-circuiting the electrodes, $e$ drops to zero suddenly. This *minimum arc voltage* may be the cathode drop, the anode drop, or the sum of the two. That it is concentrated in a very confined region is certain from some experiments which were performed in this laboratory by Mr. Paul Darby. In these experiments a driven electrode was moved very slowly toward a stationary electrode while the arc voltage excursion was observed on the cathode ray oscillograph screen. In order to provide a well-defined electrode surface the experiment was performed with point-to-plane copper electrodes in nitrogen of 99% purity and with incandescent tungsten electrodes in pure hydrogen. With the highest sweep speed available on the oscillograph the change in arc voltage always took place suddenly, i.e., discontinuously on the screen. From the mechanical constants and an estimated time resolution of the oscillograph the minimum arc voltage (m.a.v.) was found to be confined to an electrode separation of less than $10^{-4}$ cms. In low-pressure arcs the cathode region has a thickness of about one mean free path. If this is the case at atmospheric pressure, this region would have a thickness of $.8 \times 10^{-5}$ cm. in nitrogen and $.6 \times 10^{-5}$ cm. in hydrogen. The m.a.v. lies in the range 7–20 volts and depends upon current and electrode conditions.

The positive column of the high-pressure arc has received the most study, and its fundamental properties are well understood. It has been found from studies of arcs in gases under pressure[17] that the conduction and convection[18] heat transfer properties of the medium determine the steady state electric gradient $E$ and the current density $I$. Thus, in a series of gases at the same pressure $E$ increases with heat transfer, as shown by Table 2, where the positive column gradient is given for some representative gases.

**Table 2**

Gradient $E$ for Various Gases (at 10 Amps. and 1 Atm.)

| Gas | $E$ ($v$ cm.$^{-1}$) |
|---|---|
| Hg | 5 |
| A | 8.6 |
| $N_2$ | 22 |
| He | 32 |
| $H_2$ | 80 |

The gradient and heat transfer increase with pressure in each gas, as illustrated by the case of nitrogen in Table 3.

**Table 3**

Gradient-Pressure for Nitrogen Arcs (10 Amps.)

| $E$ ($v$ cm.$^{-1}$) | $p$ (Atm.) |
|---|---|
| 22 | 1 |
| 32 | 5 |
| 41 | 11.5 |
| 52 | 20 |
| 62 | 30 |

Finally, from the conduction equation $I = nekE$, the ionization equation (1), and from the Nusselt equation[18a] for the conduction and convection heat flow, the gradient current characteristic is calculated to be

$$E = a\, i^{-n}, \qquad (3)$$

which agrees with experiments on low current metal-vapor-free arcs. The exponent $n$, calculated for constants of the Nusselt equation, is in good agreement with measured values of $n = .6$, which holds for low current arcs in air, $N_2$ and $CO_2$. This equation (2) is obtained on the assumption of a constant arc temperature independent of current. Experimentally we find that the temperature shows a very small dependence on current.

The important electrical properties of the high-pressure arc are thus accounted for satisfactorily by a consideration of the heat transfer properties of the gas. Measurements show that in the welding arc the gradient $E$ is practically independent of current through a considerable range of current, and it has been suggested[16b] that the $E$-$i$ characteristic is actually positive at very high currents. If more careful measurements bear out these observations, it will be in order to examine the fundamental relationships upon which (3) rests to discover the source of a positive characteristic. When the pressure and the temperature difference are constant, the Nusselt equation for conduction and convection heat flow takes the form

$$W = \alpha D^n,$$

where $W$ is the heat loss in watts cm.$^{-1}$ length of cylinder of diameter $D$. In order for the exponent $n$ of (3) to be

zero, i.e., $E$ = constant, it is required that $m = 2$. The exponent $m$ for solid bodies lies in the range .3–.8, and for these cases the arc $E$-$i$ characteristic must always be negative. It is difficult, therefore, to reconcile a constant gradient of the welding arc with the theory of the low current arc. The explanation of a constant gradient may lie in the variation of the metal vapor concentration which is assumed constant by the theory. The variation of the effective ionization potential of the arc gas from the value of 15 volts found at low current to the 9 volts in the high current welding arc is, of course, a very important factor. Measurements of the electrical properties of the welding arc must be interpreted with care because of the nature of the experimental difficulties. The fact that the arc current is conducted through a molten globule of iron with a resistivity much increased by temperature may be sufficient to account for the positive characteristic at very high currents suggested by v. Conrady. A calculation on the basis of an extrapolated value of the temperature variation of resistivity of iron shows that at its melting point a small droplet of iron could indeed account for a potential drop of from one to three volts at high current. This quantity may be doubled, because the conduction takes place through molten iron at both electrodes, to obtain a value of 2–6 volts, which is not at all negligible in the low voltage welding arc. A "residual" voltage of from 1 to 4 volts is observed momentarily upon short-circuiting the electrodes at high current.

## CATHODE PHENOMENA

Much speculation and some experimentation have been directed to the problem of the source of electrons at the arc cathode. Compton[2] showed that in the case of the hydrogen arc experiments of Mackay and Ferguson[19] thermionic emission at the melting point of the tungsten cathode was a sufficient source of the observed cathode current density. The same is likely in the case of the cathode of the carbon arc, especially when a core is used. In the case of electrodes of copper, iron and mercury, however, thermionic electron emission seems to be ruled out definitely. None of these materials can supply sufficient thermionic emission at its melting point to explain the known high cathode current densities in these metals. It is possible that thermionic emission from the oxides of these metals may be supplying electrons in the arc. For theoretical reasons this appears unlikely. Some experiments with iron, performed in this laboratory some time ago by Mr. E. F. Hennelly, showed that at least with this material the thermionic emission from the oxide or the iron is wholly negligible as a source of electron emission in the arc. In these experiments the peak emission was observed as filaments of pure iron and oxidized iron were heated in a vacuum through the melting point. The thermionic emission was measurable, but was much too small to contribute significantly to arc current densities for either pure or oxidized iron.

Field emission[20] due to the cathode concentration of potential is a possible source of electrons in the case of a non-thermionic cathode and appears to be the most likely source in some cases, especially clean mercury. Some recent experiments[21] point to the "oxide layer effect," which has been studied[22a,b] in connection with glow discharges as a likely mechanism of emission in the atmospheric arc. In this process the high fields necessary for emission are produced by the surface charge on a very thin oxide film on the cathode surface.

In the absence of oxygen we have found it impossible to establish a steady state arc between electrodes of copper, silver or iron in the 100 volt-50 ampere range. Stability is achieved in a striking manner by oxidation of the cathode, however. It is well known that it is difficult or impossible to establish a welding arc between a clean oxide-free iron welding rod and a clean steel plate. In this case stability can be obtained, however, by repeatedly striking the unstable discharge until an oxide layer is deposited on the surface. It is for this reason that "bare" iron welding electrodes are not bare. The thin oxide film with which they are coated is very important from the standpoint of arc stability. This "oxide layer effect" is thus of fundamental importance in the welding arc.

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# STUDIES OF THE SPOT WELDING of Low Carbon and Stainless Steels*

By **WENDELL F. HESS, D.Eng.† and ROBERT L. RINGER, JR., E.E.‡**

## INTRODUCTION

THIS paper is in the nature of a progress report on the program of resistance welding research sponsored by the Welding Research Committee of Engineering Foundation, at the Rensselaer Polytechnic Institute welding laboratory. The advance program of this research was published in the March 1938 Supplement to THE WELDING JOURNAL.

As outlined in Part 1 of this program, about three months of the time of the research fellow was spent in searching the literature to find out what was known about the subject. This will be made the subject of a later report. On the whole, the literature is qualitative and informational, rather than quantitative and scientific. Also it is difficult to find much agreement among published data. This is to be expected since so much of the information published is presented with one or more pertinent facts omitted. Currents may not be given, and instead kva., often only transformer capacity, is substituted. Another factor frequently omitted is the exact size of the electrode faces in contact with the sheets, and without which current and electrode pressure are almost meaningless.

In order to completely specify a weld, so that it may be reproduced by others, the following information should be given:

1. Material welded.
   (*a*) Analysis
   (*b*) Thickness
   (*c*) Surface finish
2. Current. Actual effective secondary amperes during welding.
3. Pressure. Total electrode pressure in pounds is preferable since it ties up with a fundamental limitation of machine capacity.
4. Size of electrode in contact with sheets. Diameter is sufficient if circular, otherwise the area should be specified. This is very essential since unit pressure and current per unit area bear important relation to the quality of the resulting weld.
5. Time. This may be expressed in cycles if the frequency of the alternating current source is also specified. If the welding is by direct current using condenser or magnetic field discharge, the time constant of the circuit must be stated.

Other factors that may play a part in properly specifying a weld are: the time of dwell of electrode pressure, after the current has been cut off, and the inertia of the moving parts of the welding machine. The former may be important in order to allow the weld to pass without disturbance through its critical temperatures. The latter is important because the moving electrode must follow through when the metal fuses, to take up the decreased volume of the fused sheets. Until careful investigation shows the effects of these factors, they should probably not be required to be specified.

The specification above referred to is for the purpose of placing welds on a common basis for comparison and so that data obtained in different laboratories may be correlated. It is not the type of specification with which the designer of a spot-welded structure would be concerned.

## TESTING OF SPOT WELDS

Part 2 of our program refers to the methods of testing spot welds, for which there are not accepted standards. The following types of tests have been used with varying degrees of success:

1. *Torsion.*—In this type of test a fair approach to the measurement of the shear strength of the weld or of the material welded is obtained, depending upon whether failure occurs around the rim of the weld or through the spot. In the former case the torque will depend upon the square of the diameter of the spot weld, and in the latter case the torque will depend upon the cube of the diameter. The limitations of this type of test might be summed up as follows:

   (*a*) The enormous effect of the diameter upon the result may lead to large unsound welds made with too much energy, being rated higher than more perfect welds of slightly smaller diameter.

   (*b*) The result is expressed in terms which are not immediately useful, being in units of torque which is a type of stress not encountered in service.

   (*c*) If metal is squirted out of the spot during welding, its wedging action between the sheets will give rise to serious inconsistencies. Professor Henry F. Gray** has experimentally verified this condition.

   The value of this test lies in the fact that:

   (*a*) It gives us a means of measuring the fundamental physical property of shear strength.

   (*b*) It provides a quick and easy comparison of techniques if the foregoing limitations are taken into account.

   (*c*) The machine required to make the test is comparatively inexpensive to build.

   (*d*) It is about the only approach which we have to a measure of the ductility of a spot weld.

2. *Shear, or Tension on a Lap Weld.*—In this case failure may occur in shear through the weld cross section, or by failure in the plate at the stress concentration point at

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the edge of the weld. The strongest welds in thin materials usually fail in the latter manner. The objection to this type of test lies in the fact that the stress concentration and the necessary eccentricity of loading cause distortion of the pieces so that pure shear is never obtained. It also seems necessary to set up arbitrary standards as to length and width of test specimens as well as location of the spot in order to insure reproducibility of results.

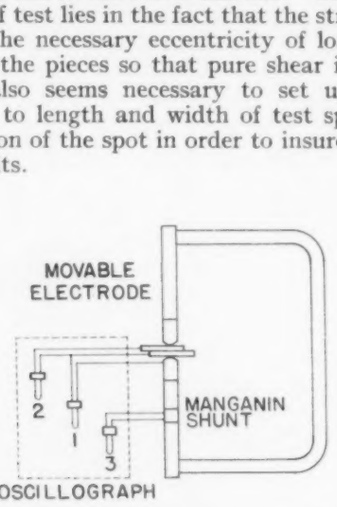


Fig. 1—Arrangement of Oscillograph Connections for Measurement of Contact Resistances

The chief advantages of this type of test are the simplicity of preparation of the specimen and of making the test. The eccentricity involved in making this test may not be too serious a disadvantage since such eccentricity usually occurs in an actual structure.

Other advantages are the availability of tension testing equipment, the fact that much data of this type is already at hand, and the fact that the result is expressed in units which closely approach the needs of the designer.

3. *Tension.*—Pure tension at right angles to the plane of the welded sheets is extremely difficult, if not impossible, to obtain. Attempts to realize this condition in practice almost always result in what is more of a peeling type of test with resultant stress concentration at the edges of the spot. Very low values can be expected if the yield strength of the material is high compared to its cohesive strength. If the yield strength is low, the stress concentration will be greatly reduced and the results may show comparatively high values.

As at present used this type of test may tend to peel the weld apart from four directions or from two. In the former case with high yield strength, there is an approach to three-dimensional stress conditions which is likely to give rise to an apparent brittleness in an otherwise tough and ductile material.

4. *Microscopic Examination.*—Our experience has shown that examining under a microscope a polished and etched cross section of a spot weld gives very definite indication as to whether the weld was made under the best possible conditions. Too little energy, sufficient energy and too much energy, all leave their characteristic indications. The depth of penetration of the fused weld is closely related to maximum physical properties. From forty to seventy per cent penetration is likely to be associated with the best properties.

Too little energy is evidenced by a small nugget of less than normal penetration, by no nugget at all or by a non-columnar structure. Too much energy is indicated by excessive penetration, banding, cavitation, expulsion of metal, serious indentation, cracks and grain coarsening.

Probably the most important service condition to which a spot weld is subject is that due to the tendency of the load to buckle the sheet between welds, which frequently exists in a structure where two sheets are spot welded together at several points in line, or where a sheet is welded to a stiffening member. In this case there is combined shear and tension at the edge of the weld. Failure occurs either due to localized diagonal shear through the sheet at the edge of the weld, or by tearing through the weld itself starting with tensional stress concentration at the tip of the weld. This type of stress would occur in service in railroad rolling stock, and aircraft structures. Failures may be of the fatigue type, or even in some cases under initial application of load. There is no satisfactory test yet devised to simulate this condition. Two other types of tests are also needed: first, a satisfactory impact test; and second, a non-destructive test.

The tests selected for evaluating welds made during the course of this investigation were: first, the shear test, or tension on a lap weld; and second, microscopic examination. For various pressures, times and electrode sizes, the currents required to give the best welds were evaluated by these means.

## ELECTRODES

The electrode material used so far in this investigation is a copper alloy of approximately 80 Rockwell B hardness, 85 per cent electrical conductivity and yield point of

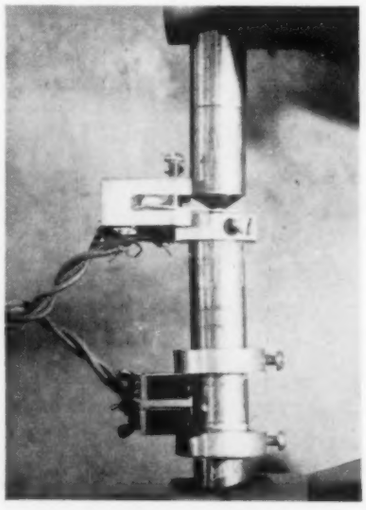

Fig. 2—Manganin Shunt Inserted in Electrode Holder with Potential Connections in Place and Potential Connections to Sheets and Electrode

60,000 psi. We have used electrode face diameters of $^1/_8$ inch and $^1/_4$ inch. Plans are under way to use electrodes of higher hardness and lower electrical conductivity. Our purpose in doing this is to determine whether the sacrifice of electrical conductivity, which ordinarily accompanies greater hardness, has any undesirable consequences. The desire for greater hardness is based on our experience with stainless steel in which definite and worth while improvements in quality resulted from the use of unit pressures of 50,000 psi, which is too close to the yield point of the material which we used. We also worked at 65,000 psi, with still further improvement, but we have not yet had the opportunity of working with an electrode which will not deform too readily at this pressure. With 0.029 inch annealed and pickled mild steel, an electrode pressure of 16,000 psi gave very good results.

With regard to electrode shape we began by using dome shaped tips with four inch radius spherical surfaces

but soon found that these flattened and kept changing area as the experimental conditions of pressure and current were varied. Thereafter the practice of machining flat faces of the required diameter with 30 degree sloping sides was adopted, with marked improvement. After machining, the tips are placed in the holders and then aligned by bringing the electrodes together to a snug fit against a fine, thin, flat tungsten file, which is worked around to bring the surfaces into exact alignment, with great care to avoid rounding the edges. A simple but very effective test for the alignment of electrodes is to take a piece of the material which is to be welded and wrap a sheet of paper around it, after which the electrodes are brought down in contact with the paper under pressure. If the electrodes are in perfect alignment, the uniformity of pressure over the surface will be indicated by a perfectly circular impression which is more translucent than the rest of the paper. Experience showed us that it is not possible to obtain consistent results by any sort of hand dressing of the electrode tips when they lose their shape due to too high pressure or too heavy current.

At this point it seems proper to state that, contrary to popular belief, serious and undesirable indentation of the electrode into the sheet is not due primarily to high pressure but to an excessive application of energy. Even with very high pressures, very little indentation resulted in the maximum strength welds where the current was just sufficient to give a good sized nugget of forty to seventy per cent penetration, and not sufficient to cause expulsion of metal.

## CONTACT RESISTANCES

We were let to set aside, for the time being at least, that portion of our program which planned a simple direct current measurement of contact resistances, first at room temperatures and then at elevated temperatures, by the knowledge that Dr. Frank J. Studer†† had become interested in and possessed facilities for experimental work along these lines.

When preliminary measurements showed that oscillographic determination was feasible, we proceeded to this method of attack. The oscillographic measurements should be made under conditions which would include those which gave the best possible welds. Hence, a large amount of preliminary work was necessary to establish optimum conditions of current, pressure and time. These preliminary studies were undertaken by choosing from experience definite values of time, selecting several pressures, and gradually increasing the current under each of the above conditions up to and beyond the value which would give a weld of maximum strength. The times in each case were fixed by a thyratron control equipment using ignitrons in the primary leads to the welding transformer. Pressures were applied by a regulated air cushion, indicated by a gage which was calibrated in terms of actual pressure at the electrodes by a lever system and platform scale. For the quarter inch welds, the dwell time of the electrode pressure after the cutting off of the current was adjusted to be 100 per cent of the weld time, except in the case of the 20 cycle welds in annealed mild steel, when the dwell was reduced to 75 per cent.

The different values of current for the preliminary tests were determined by careful adjustment of the primary voltage given by a motor-generator set, by changing taps and connections on a transformer in the welding machine, and finally by phase control of the firing of the ignitron tubes in the thyratron control equipment. Four welds were made at each of nine values of current for physical tests to establish optimum currents for each of the possible combinations of three times and three pressures. Two different sizes of electrode, of one type of material were used on one thickness of annealed and pickled mild steel, and one thickness of polished 18–8 stainless steel. This data awaits translation of the arbitrary settings of current to actual amperes before it can be published, which involves a large amount of oscillographic work, unless a satisfactory and simpler method of current measurement can be used. Of course the oscillographic work will tell a much more complete story, so that the additional time will be partly compensated for by the value of additional data.

The method of measuring the current to be used in the determination of contact resistance was to use a calibrated electromagnetic oscillograph to measure the drop in potential across a manganin shunt. Figure 1 shows a diagrammatic sketch of the arrangement of the shunt and of the potential connections for determining sheet-to-sheet and electrode-to-sheet voltages. The apparatus

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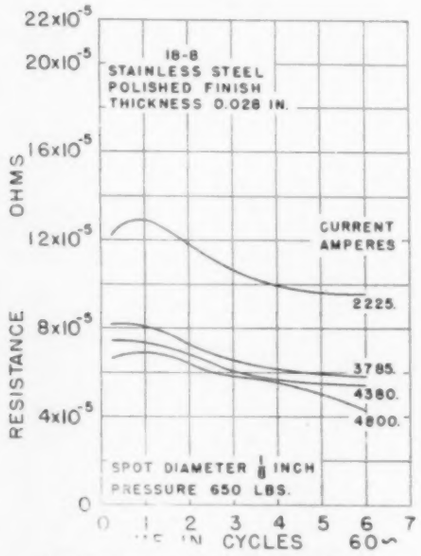



Fig. 3—Sheet-to-Sheet Contact Resistances for 1/8-Inch Spot Welds

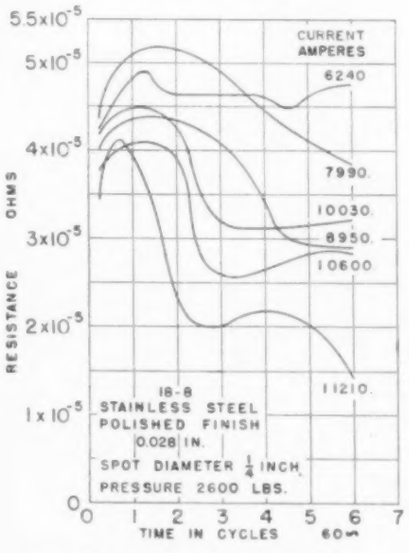



Fig. 4—Sheet-to-Sheet Contact Resistances for 1/4-Inch Spot Welds

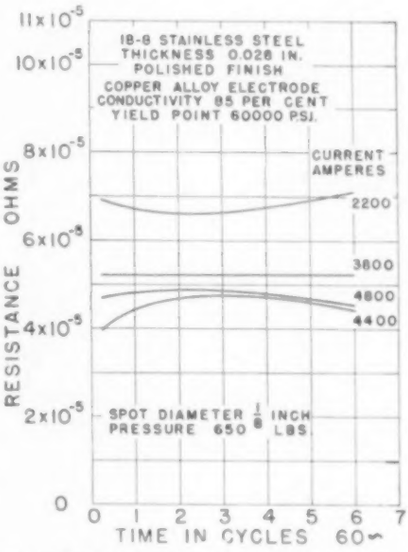
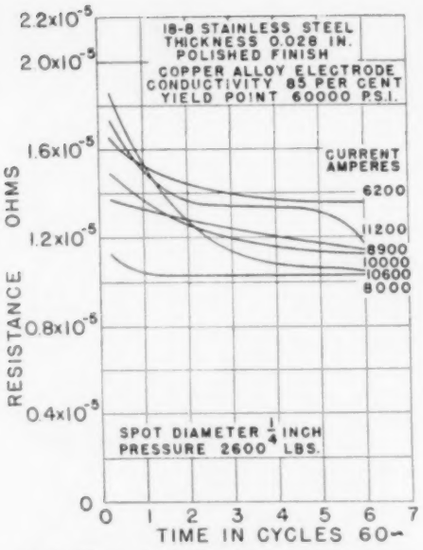



Fig. 5—Electrode-to-Sheet Contact Resistances for 1/8-Inch Spot Welds




ig. 6—Electrode-to-Sheet Contact Resistances for 1/4-Inch Spot Welds

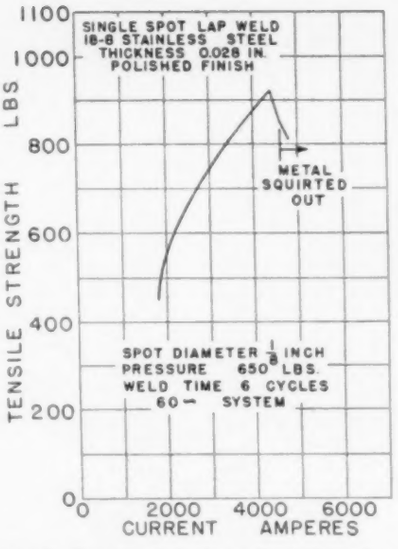



Fig. 7—Tensile Strength on Single Spot Lap Welds as a Function of Current for 1/8-Inch Spot Welds

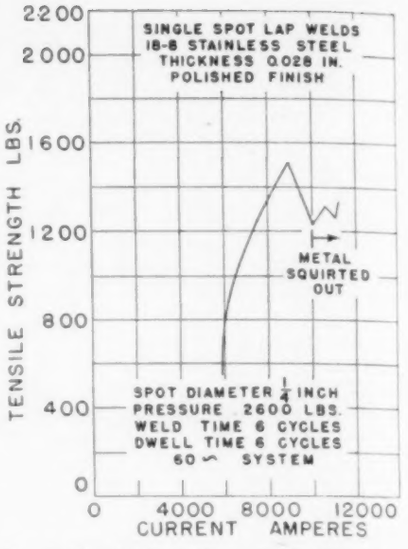



Fig. 8—Tensile Strength on Single Spot Lap Welds as a Function of Current for 1/4-Inch Spot Welds

used is illustrated by the photograph in Fig. 2. The shunt consists of a hollow cylinder of manganin silver-soldered into the water-cooled electrode holder. Potential connections are the usual wedge type commonly applied for the precise determination of low resistances in the Kelvin Double bridge. The resistivity was determined with the manganin in the form of a hollow cylinder about six inches long in the Kelvin Double bridge. Calculation shows that the skin effect of this bar is negligible.

The contact resistances were calculated from measurements of peak current and peak voltage at each half cycle on oscillograms made with a calibrated electromagnetic oscillograph and a calibrated shunt for the current measurement.

In the present paper we are including contact resistance data for 1/8-and 1/4-inch spot welds in 0.028-inch polished stainless steel made in six cycles with an electrode pressure of approximately 50,000 psi. Figures 3and 4 show these contact resistances between sheets expressed as a function of time during the making of the weld for various currents. These resistances are so measured that they include the resistance of one sheet. Due to the absence of complete knowledge of the behavior of this material up and through the melting point, it is not possible to make an accurate correction for this resistance. However, calculations show that it is of the order of the resistance shown, indicating that contact resistance between polished sheets of this material must be very low.

Reference to Fig. 3 shows that for currents of the order of 4400 amperes which gave the strongest weld, the resistance drops about thirty per cent from its initial peak value during the making of a weld. This is probably due to the gradual formation of more intimate contact due to softening and gradual growth in size of the fused portion of the weld. 4800 amperes was considerably too high a current for this weld as evidenced by expulsion of metal during welding, serious indentation and loss of strength. 3800 amperes differed from the best value only in the size of the resultant spot, which was slightly smaller. 2200 amperes gave a weld of about seventy per cent maximum strength and thirty per cent penetration. This latter curve indicates an interesting general tendency for curves of this type to rise initially before falling off. This is no doubt due to two opposing tendencies: first, a tendency of the resistance of the material and probably the contact resistance to rise with temperature; and second, the tendency of this latter resistance to disappear as the weld becomes larger and the contact becomes more intimate. All of the curves in Fig. 4 exhibit this tendency to rise at first and then fall. Figure 4 shows some further interesting tendencies, namely, the tendency of higher currents to build up the fused portion and thus reduce the contact resistance earlier in the weld period. For example, the 8900-ampere weld seems to build up its full-sized nugget in about five cycles; the 10,000 ampere weld, in about three cycles; the 11,200 ampere weld, in about two cycles. Another tendency exhibited by the 11,200-ampere weld is a sharp falling off in resistance during the last one and a half cycles due to serious indentation resulting in this case in a reduction to approximately the thickness of one sheet. All three welds made with currents higher than 8900 amperes suffered a loss of metal by squirting and a consequent reduction in strength. The 6200-ampere current did not result in a completely fused weld and had a strength of about half that of the best weld. Notice that these curves show that to make the best weld with equal unit pressures a current of 4400 amperes is required for the 1/8-inch spot, and 8900 amperes for the 1/4-inch spot, showing that the current varies with the diameter, which in this case has a ratio of two to one, and not as the area which varies in the ratio of four to one. In other words, the current densities are inversely proportional to the diameters.

Figures 5 and 6 show the electrode-to-sheet contact resistances for the same conditions as Figs. 3 and 4, respectively. These contact resistances are much lower than the sheet-to-sheet resistances, and seem to remain nearly constant during the weld cycle, except for a tendency to drop at the start, due to more intimate contact. The drop in resistance during the last part of the 11,200-ampere weld corresponds with the similar drop in the sheet-to-sheet resistance for this current, and is probably due to the burying of the electrode into the sheet which took place.

## OPTIMUM CURRENTS

In order to determine the optimum conditions of current, pressure and time for 1/8-inch and 1/4-inch welds in

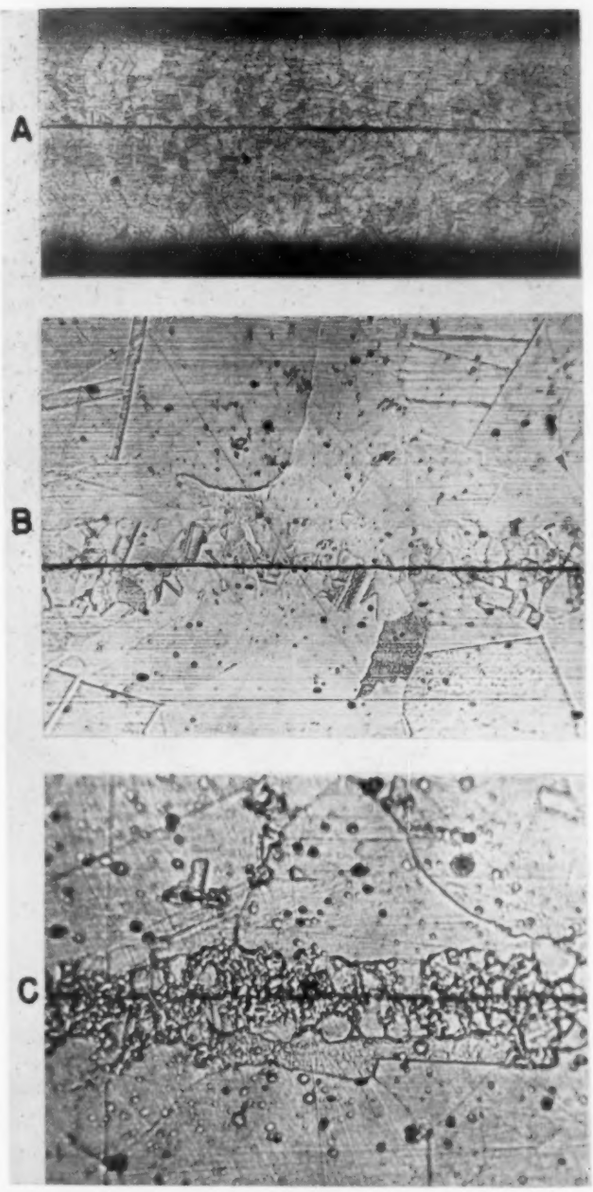



**Fig. 9—Initial Stages in the Development of a Spot Weld in 0.028-Inch Polished 18-8 Stainless Steel**

A. Surface Sticking and Incipient Fusion at 32×
B. Surface Sticking at 500×
C. Incipient Fusion at 500×

0.028 inch polished 18–8 stainless steel, times of 2, 6 and 10 cycles were chosen. Unit pressures of 30,000, 50,000 and 65,000 psi were found to give increasingly stronger welds. An electrode pressure of 50,000 psi was about the maximum which could be satisfactorily used with the electrode material which was available, which had a yield point of about 60,000 psi.

Figures 7 and 8 show the tensile strength of single spot lap welds as a function of current in 0.028 inch polished 18–8 stainless steel, using a unit electrode pressure of 53,000 psi, for $^1/_8$-inch and $^1/_4$-inch spot welds, respectively. Notice that the strength rises smoothly with the current and then falls off in an erratic manner when a value of current is reached which causes metal to be expelled from the weld. Lower pressures permit the expulsion of metal to take place at lower values of current, with the result that it is not possible to reach such high strengths. When squirting of metal occurs, cavitation, serious indentation, and lowered strength follow as a consequence. It will be noted that by doubling the diameter of the weld and using the same unit electrode pressure, it was possible to double the current without squirting and the resulting weld was fifty per cent stronger.

## MICROSCOPIC EXAMINATION

Throughout the course of the preliminary studies to establish optimum conditions of current at the various pressures and with various timing, samples were taken for microscopic examination. This was done for both mild and stainless steel welds and showed some very interesting correlation with the physical tests. It also helped to show, for example, that 30,000 psi was insufficient for the welds in 0.028-inch polished stainless steel. As a general tendency it showed that for maximum strength, the penetration of the fused portion varied from about 40 to 70% with a tendency for the best $^1/_4$-inch welds to have the lower penetration and the best $^1/_8$-inch welds to have the higher penetration. In this respect the welds in the mild steel and stainless steel seemed to have the same tendencies. The best welds always exhibited regular, clean, columnar structures and showed only slight indentation and no cavitation. Welds with either insufficient or excessive energy showed a number of interesting tendencies which will be discussed in connection with the accompanying microphotographs. We shall first present a number of picturse showing the various steps in the development of stainless steel spot welds, including evidence of insufficient and more than sufficient current.

Photograph A of Fig. 9 shows the initial stages in the development of a spot weld at 32×. Over most of the area of contact there is merely surface sticking, which is shown at 500× in B of Fig. 9. To the right of the center of A is a darker area which is shown in C of Fig. 9, at 500×. This area shows incipient fusion along the line of contact.

A of Fig. 10, at 32×, shows the third stage in the development of a spot weld, which is the production of a non-columnar nugget having ragged edges, exhibiting

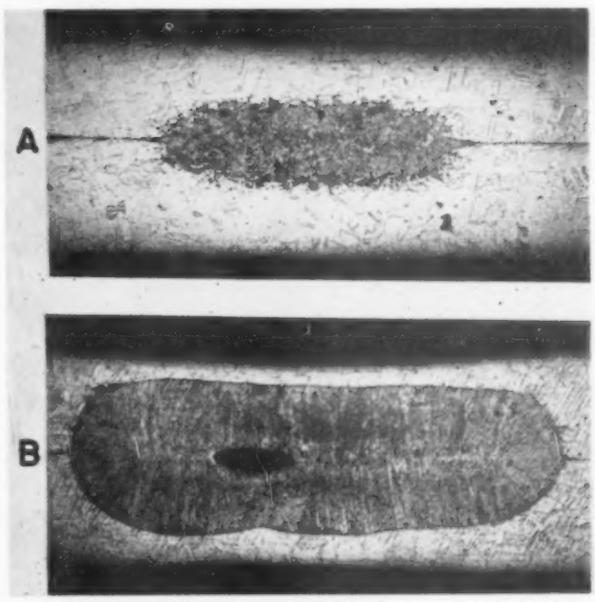



**Fig. 10—Further Stages in the Development of a Spot Weld in 0.028-Inch Polished 18-8 Stainless Steel**

A. Third Stage Non-Columnar Structure 32×
B. Weld Made with Excessive Energy with Too Low Electrode Pressure 32×

incipient fusion along grain boundaries. It is probable that this structure is due to raising the metal into the narrow temperature range where it is pasty, between the solid and the liquid state. This weld was made with about 32,000 psi of electrode pressure and represents the strongest weld that could be made at this pressure without squirting of metal. Its strength was about two-thirds that which could be obtained in the same time of two cycles by increasing the pressure to 50,000 psi. B of Fig. 10 shows the result of additional energy which produced a large cavity due to the expulsion of metal during welding.

A, B and C of Fig. 11 show a series of stages from too little to too much current. A again shows the non-columnar structure which had a strength of about 75% of that of B. Notice that in the center of this weld a very small portion of the columnar structure has formed. B shows a weld of maximum strength for these conditions, which, in this case, were two cycles and 65,000 psi electrode pressure. Notice the very slight indentation in spite of the enormous pressure. This is a general tendency shown throughout the work, that the best welds made with just sufficient energy do not have serious indentation even with high pressure. C shows the result of an excessive amount of energy; large central cavitation, serious indentation and cracking in the unfused sheet due to the severity of the contraction following the expulsion of metal. Notice at least three small grains at the edge of the fused zone which have been torn loose and have fallen out in the preparation of the specimen.

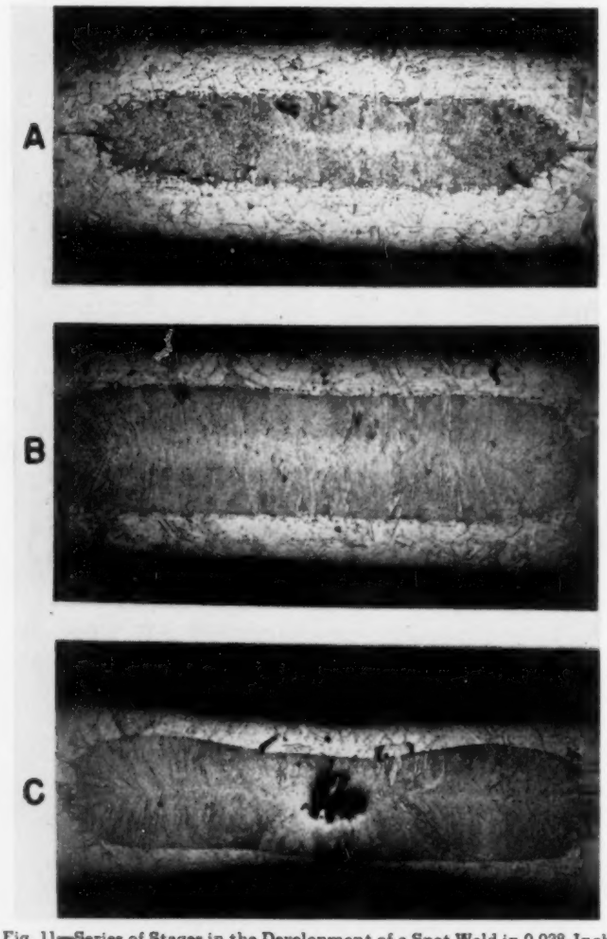



**Fig. 11—Series of Stages in the Development of a Spot Weld in 0.028-Inch Polished 18-8 Stainless Steel at 32X**

A. Too Little Current. Columnar Structure Commencing to Form at Center of Large Non-Columnar Weld
B. Weld of Maximum Strength
C. Excessive Current Resulting in Cavitation, Indentation, and Tearing of Grains in Sheet

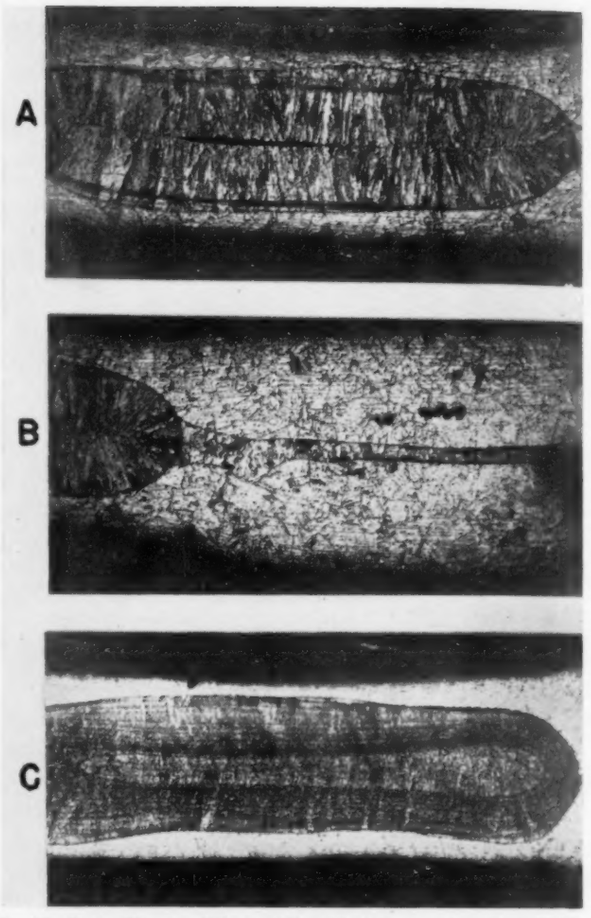



**Fig. 12—Series Showing Effects of Too Much Energy in a Spot Weld in 0.028-Inch Polished 18-8 Stainless Steel at 32X**

A. Cavitation, Banding, and Indentation
B. Trail of Metal Expelled from Weld
C. Very Pronounced Banding in 10 Cycle Weld

A and B of Fig. 12 show two photographs of a weld made in six cycles with an excessive amount of energy. Notice the large central cavity in A and the trail of squirted metal in B. Notice another evidence of excessive energy found in welds made in more than two cycles, namely the banding near the surface of the fused weld. C shows this latter tendency to a much greater degree, and was taken of a weld made in ten cycles. In all our experience so far, we have not observed banding in welds made with just sufficient energy. When banding is exhibited the columnar structure is always more pronounced near the center of the weld where the metal has solidified more slowly.

A, B and C of Fig. 13 show a series of stages in the development of a spot weld using $^1/_4$-inch electrodes. These stages proceed from incipient fusion along the line of contact and around the grain boundaries, at the interface between sheets, to the completely fused maximum strength weld shown in C. Note the rather large incipient fusion zone in B, with only a very thin columnar portion along the center of the weld. This incipient fusion zone still persists at the end of the weld in C. Weld C was made in six cycles, at 50,000 psi electrode pressure, and shows good clean columnar structure.

A of Fig. 14 shows a beautiful section of columnar structure of a weld made in two cycles at 32,000 psi. This weld is really shown because of its interesting structure. The central portion of this weld was seriously in-

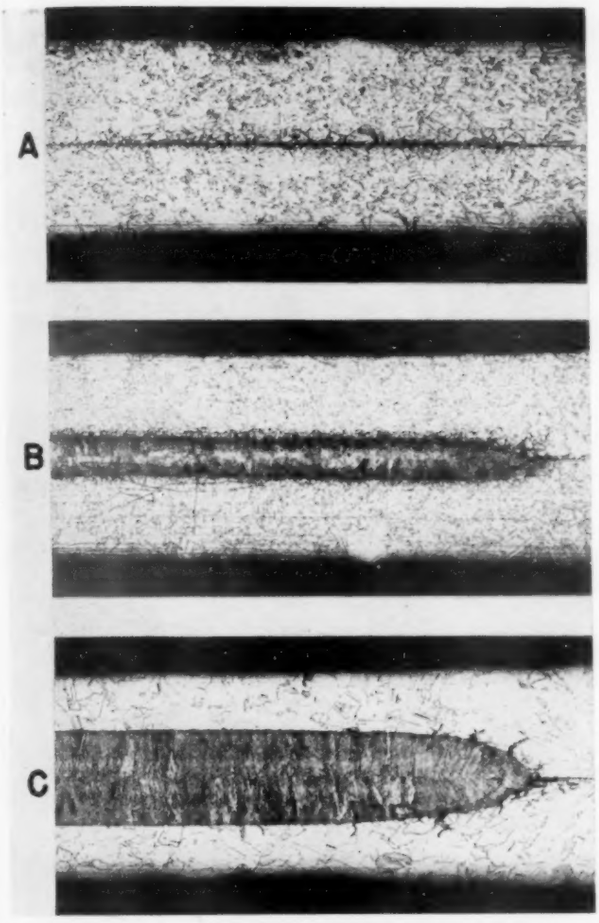



**Fig. 13—Series of Stages in the Development of a Spot Weld Using 1/4-Inch Electrodes on 0.028-Inch Polished 18-8 Stainless Steel at 32X**

A. Incipient Fusion Around Grain Boundaries at Interface
B. Large Zone of Incipient Fusion with Thin Columnar Structure at Center
C. Completely Fused Maximum Strength Weld. Slight Incipient Fusion at End

dented because again, as was shown in the 1/8-inch welds, this pressure was insufficient to avoid expulsion of metal. B and C show "welds" made in a solid sheet of stainless steel 0.069 inch thick, with amounts of energy which would have been somewhat excessive for welds in two sheets of this total thickness. These were taken to show that the fusion zone at the center of a weld is not determined entirely by the development of heat due to contact resistance. Heat may be localized at the central portion of a weld by the differential cooling to which the surface in contact with the electrodes is subjected, as compared with the portion of the metal at the interface between sheets.

The following photographs illustrate welds made in 0.029-inch annealed mild steel. A of Fig. 15 demonstrates a good weld made in twelve cycles at an electrode pressure of 16,000 psi. B shows another good weld made in four cycles. Notice that the heat zone of this latter weld is confined to an area close to the fused zone and that it is of only one type. A shows the three typical heat-affected zones which commonly surround welds made in mild steel. Evidence indicates that the lightly etched zone between the two other zones consists of metal which has been completely transformed into austenite during the process of making the weld. The zone nearest the fused portion is, therefore, assumed to be an incipient fusion area, and the outer zone must be the area which has been raised to temperatures between the lower and upper critical, where transformation to austenite has been only partial. C of Fig. 15 shows a very tiny nugget surrounded by very pronounced zones, the first of which shows incipient fusion which is more pronounced around grain boundaries near the ends of the nugget. This zone is surrounded by a large zone of complete transformation, outside of which appears the partial transformation zone.

A and B of Fig. 16 give evidence of the character of the intermediate zone. Notice in A that the intermediate zone has been extruded into the space between the sheets, forcing them apart. Also notice that the outer zone has not moved. This indicates that the metal in the intermediate zone was in the most plastic condition at some time during the making of the weld. This condition of being plastic is characteristic of austenite. B is a photograph of the extruded metal shown in A, magnified 500 times. The fact that this region etched very lightly and

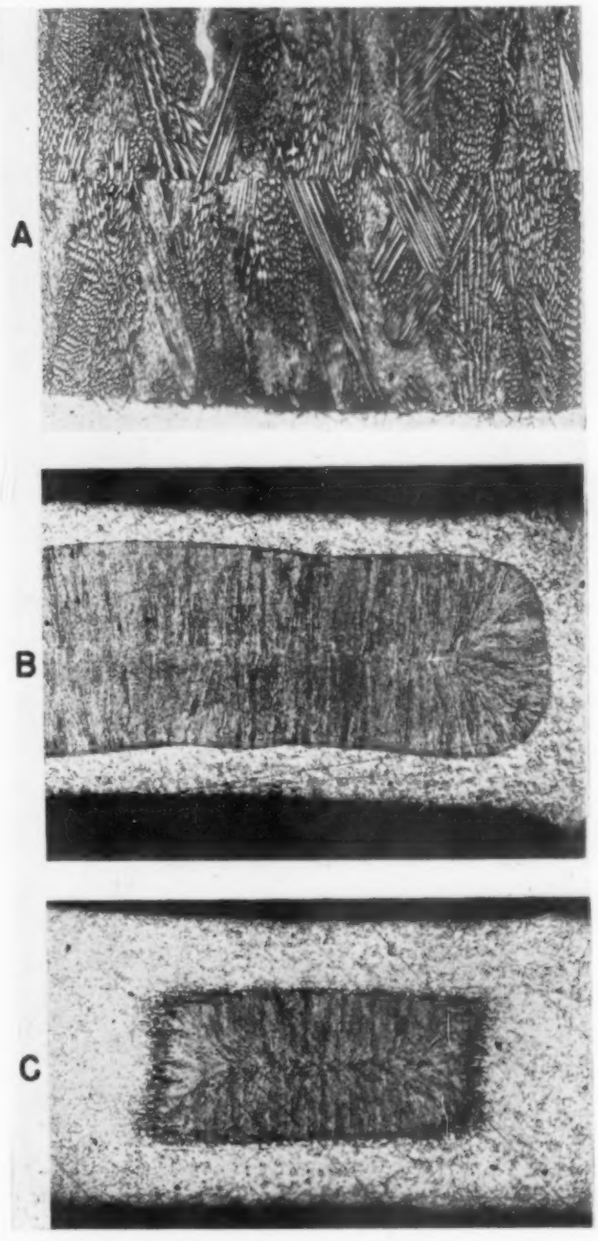



**Fig. 14—Interesting Weld Structures in Polished 18-8 Stainless Steel**

A. Beautiful Columnar Structure of Weld Made in Two Cycles at 150X
B. "Weld" Structure in 0.069-inch Solid Sheet Stainless Steel 32X
C. Similar "Weld" Using Less Energy Than for B., 32X

is acicular in structure, is evidence of the fact that this metal was transformed to low-carbon martensite upon cooling, the carbon remaining in solution. Before leaving these pictures, notice in A the cracks developed in the columnar portion by the violence of the extrusion process. This weld was made in twenty cycles at 32,000 psi. Greatly excessive energy is responsible for the very large indentation.

If it were possible to bring all of the metal at the interior contact surfaces into the austenitic condition which we have just been discussing, it should be possible to make a truly plastic weld. However, the fact that this weld is made in such a comparatively short time, and therefore transforms upon cooling into martensite, indicates that the weld should be harder than the sheet material and might, therefore, be brittle. A weld which is practically entirely of this structure was made in twelve cycles at 10,000 psi. A portion of its structure including the line of contact is shown in C of Fig. 16, at 500×. Notice that the structure is almost exactly identical with that shown in B of this figure except that traces of the austenitic grain envelopes are visible in C and not in B, at least those in B are very much finer. This is probably due to the fact that the metal in B has flowed during extrusion in the austenitic condition, thus breaking up the austenitic grains.

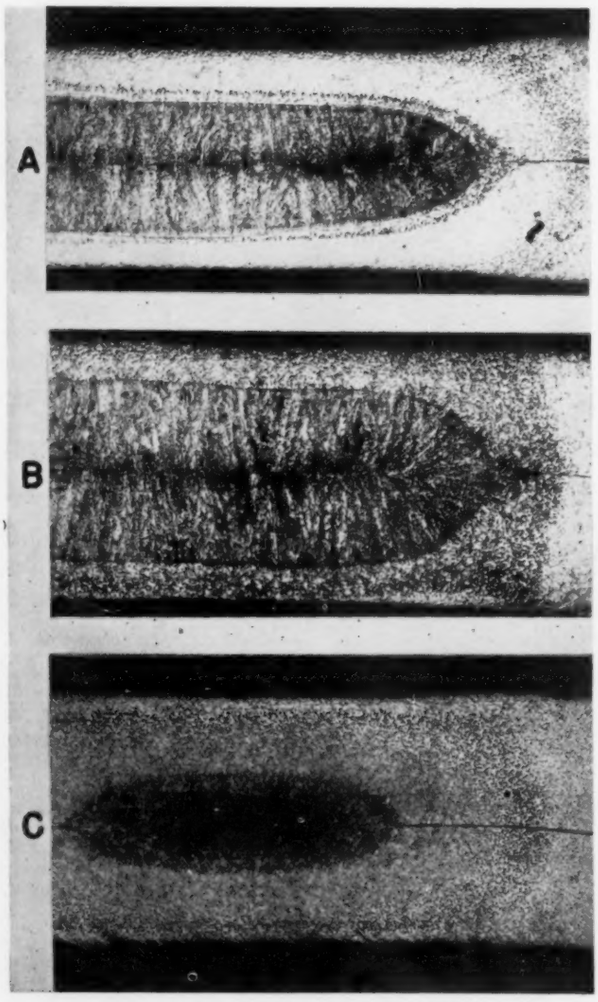



**Fig. 15—Welds Made in 0.029-Inch Annealed Mild Steel at 32X**

A. Good Weld Made in 12 Cycles with Electrode Pressure 16,000 Psi
B. Good Weld Made in 4 Cycles
C. Very Small Fused Weld Surrounded by Three Pronounced Heat-Affected Zones

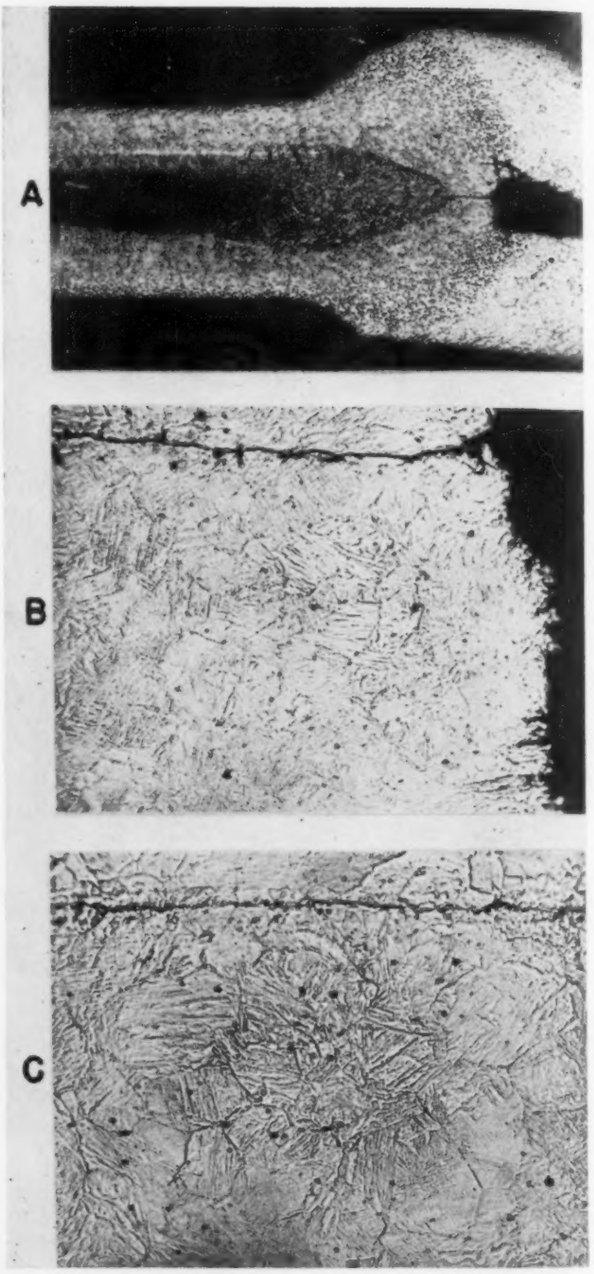



**Fig. 16—Evidences of the Character of the Intermediate Heat Affected Zone Surrounding Spot Weld in Annealed Mild Steel**

A. Showing Extrusion of Intermediate Heat-Affected Zone Indicating Its Plastic Condition as Compared with Weld and Outer Zone at 32X
B. Showing Intermediate Heat Affected Zone at 500X Illustrating Acicular Structure Characteristic of Low-Carbon Martensite
C. Section of Weld Entirely of Martensitic Structure at 500X. True Plastic Weld, Made in 12 Cycles with an Electrode Pressure of 10,000 Psi

A of Fig. 17, at 100×, illustrates a weld made with $^1/_4$-inch electrodes in four cycles in mild steel at 16,000 psi, with an energy which was slightly excessive. The excessive energy was indicated by the fact that metal was expelled from the weld and also by the microphotograph B at 100×, which shows grain coarsening which took place at the center of the nugget where cooling was slower. The weld having been made in comparatively short time, the outer portion was cooled sufficiently rapidly after fusion to give a finer columnar structure.

C is a photograph, at 500×, of metal squirted from the above weld. The squirted metal was undoubtedly fused and the similarity of its structure with that of the central

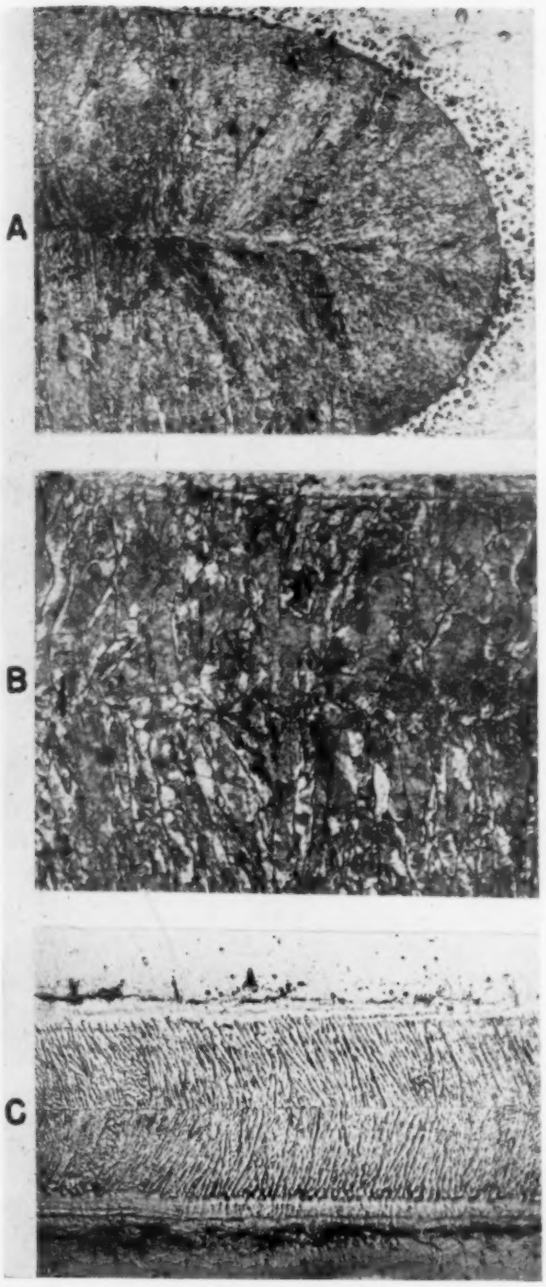



**Fig. 17—Phenomena in the Spot Welding of Annealed Mild Steel**

A. Good Columnar Structure at 100×
B. Coarsened Grain Structure in Same Weld at Center of Nugget Indicating Excess Energy 100×
C. Section of Metal Expelled from Same Weld Between Sheets at 500×

portion of spot welds indicates that they also have been fused in the process of formation. Notice that the direction of the columnar structure, with respect to the direction of the expelled metal from left to right, indicates that the freezing progressed from the outer portion inward while the metal was still traveling away from the weld. The line through the center of the squirted metal is of course the line of interference of the columnar grains as they grew toward one another.

A of Fig. 18, at 100×, illustrates grain coarsening similar to that shown in B of Fig. 17, but taking place near the end where metal was expelled. This weld was made in twenty cycles with excess energy. B and C of Fig. 18, at 32×, show a weld which was made in four cycles at 10,000 psi in which the excessive energy was sufficient to cause 100% penetration of the weld metal to the surface of the sheet. The contraction of this weld was such as to produce a tear almost completely through the center of the weld. This weld not only shows 100% penetration, but also practically 100% grain coarsening.

The stainless steel specimens were etched electrolytically with a ten per cent solution of oxalic acid. The best etchant to develop the heat-affected zones which surround mild steel welds was found to be four per cent picral. This solution also developed the columnar structure of the fused weld to the best advantage.

## RESULTS

The results thus far in the program of resistance welding research indicate that:

1. The maximum strength always occurs for the maximum current which can be used without expulsion of metal during welding.
2. Expulsion of metal during welding should be avoided to prevent cavitation, indentation, cracking and loss of strength.

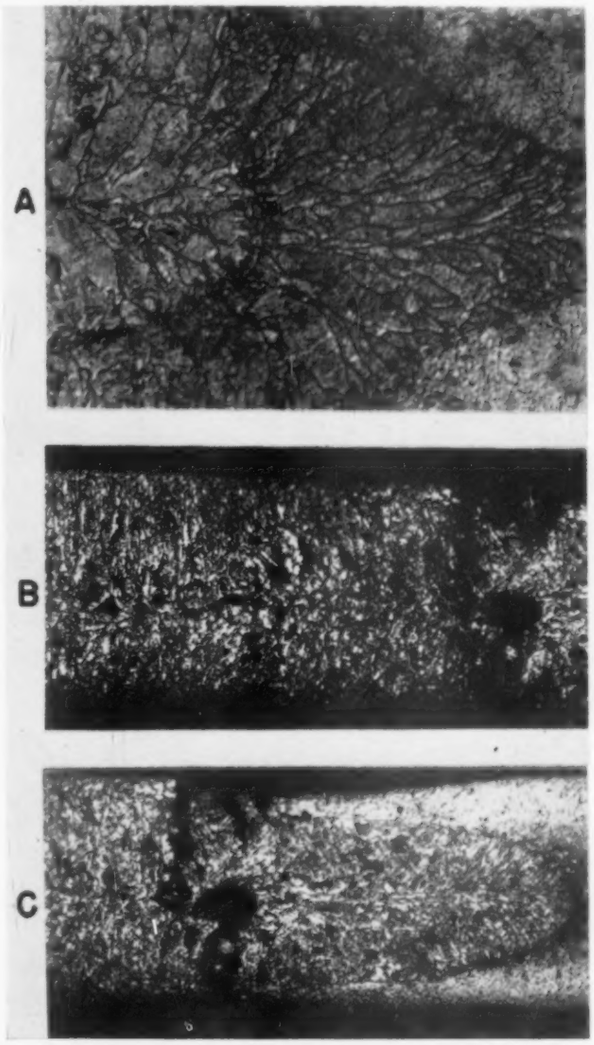



**Fig. 18—Structures Resulting from Very Excessive Energy Applied to Spot Welds in Annealed Mild Steel**

A. Grain Coarsening Near the End of Weld from Which Metal Had Been Expelled at 100×
B. & C. 100 Per Cent Penetration of Weld Through Sheets with Tear Through Center of Spot Due to Contraction at 32×

3. A penetration of 40 to 70 per cent of the sheet thickness by the fused weld is associated with the best physical properties, which confirms the results of other investigators.

4. Unit pressures as high as 50,000 psi are desirable in the spot welding of 0.028-inch polished 18–8 stainless steel. Even somewhat higher pressures than these may be preferable when electrode materials are available which will stand up under such conditions.

5. The high unit pressures which are desirable for welding stainless steels may be a serious limitation on the capacity of many machines designed for the welding of plain low-carbon steels.

6. Great care should be taken in the careful alignment of electrode tips to insure uniformity of pressure and maximum freedom from expulsion of metal during welding.

7. Microscopic examination of welds made in 2, 6 and 10 cycles indicates that the welding time may be safely carried to at least 10 cycles without appreciable carbide precipitation. A word of caution should be injected: currents must be under accurate control and electrode surfaces must be in such condition and alignment that localized concentrations of current will be avoided.

8. Microscopic examination of polished and etched cross sections affords an excellent insight into the quality of spot welds.

9. Measurement of contact resistances during spot welding is perfectly feasible, and seems to offer a fruitful avenue of investigation.


### ACKNOWLEDGMENT

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# PROGRESS IN COPPER WELDING*


By I. T. HOOK† and C. E. SWIFT‡


### FOREWORD

THE coppersmiths and equipment fabricators have felt for a long time that the copper industry should supply them (*a*) with a copper sheet that is readily weldable and (*b*) a copper welding rod that would be suitable to use therewith. In line with this demand, we started some two years ago to develop materials in sheet and rod that would, from the standpoint of structural properties and corrosion resistance, be acceptable as copper and still be more weldable than the usual tough pitch copper sheet connected with the various available welding rods.

This development work is, at this time, still incomplete so that we shall not attempt to present a final answer. However, progress has been made and our contribution may be of some value to the industry. At least, we may save others, interested in these objectives, from some expensive and unnecessary duplication of effort. In this report, attention is directed more particularly to the evaluation of the welding properties of copper welding rods commercially available. For the most part, discussion of new alloys will be left to a later paper.

### PREVIOUS WORK

In a previous paper,[1] we reported excellent progress made by the industry in the welding of copper. Copper locomotive fire-boxes were repaired by fusion welding in Germany as early as 1919 and completely welded in 1923. Most of this early work was done on arsenical tough pitch copper. In the past ten years, most of the locomotive fire-boxes abroad have been built or repaired by fusion welding. More recently, deoxidized copper in large sheets was brought out in England and sold as welding copper.

In this country, where the locomotive fire-box of copper is non-existent, comparatively little fusion welding of copper was done until the brewing industry got its new lease of life in 1933 followed by the distilling industry in 1934. Fabrication of copper brewing and distilling equipment, thus brought sharply into focus, was found to be most economically accomplished by fusion welding.

New filler rods were tried and new welding methods developed. For the most part, electrolytic, tough-pitch copper sheet continued in use though deoxidized copper sheet was available at a small premium.

During this period, the welding of copper by the long or high-voltage carbon arc was developed.[2] This method overcame, to a certain extent, the weakness in welds made in oxygen-bearing copper noted by many operators and explained by Le Grix,[3] Miller,[4] Wyman[5] and others. These explanations show such weakness of fusion welds in copper to be due to the cuprous oxide existing in the usual tough pitch copper. The use of deoxidized copper sheet and a welding rod containing a suitable deoxidizer is the most logical remedy.

However, Chaffee[6] and Swift[7] show that, where a carbon arc of an intensity sufficient to give a relatively high


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speed of welding, i.e., 10 inches or more of welded seam per minute, welds of satisfactory strength can be obtained.

## EARLY DIFFICULTIES

The greatest single obstacle to the welding of copper is undoubtedly occasioned by its high *thermal conductivity*. This property, very useful in itself and very desirable in the equipment made up with copper sheets and tubes, calls for (*a*) a very high concentration of heat in the welding zone or (*b*) a very high level of preheat in the surrounding area. The gas welding operators were first to learn this and provide blowpipes of a suitable capacity. Hence, the oxyacetylene welding of copper preceded the successful arc welding of copper (except in sheets of $^1/_8$ inch thickness or less) by more than a decade.

In oxyacetylene welding of copper, preheat is frequently used to overcome the high thermal conductivity while in carbon arc welding preheat is seldom used. Martin[8] prefers to use two oxyacetylene blowpipes, the first as a preheating agent in advance of the second which is used for welding or both used for welding after the plates are given a sufficient preliminary temperature by playing one or both of the torches on them. *La Soudure Autogene*[9] tells of a method, common in Europe, in which two torches are used simultaneously from opposite sides of the sheets. This makes a very high concentration of heat in the welding zone but can be employed only for vertical welds. This method is also described by the *Deutsches Kupfer-Institute*.[10]

Many operators, however, prefer to use a less expensive source of preheat as city gas or charcoal. Mashl[11] for instance used, with entire success, a charcoal fire for preheating some heavy copper headers. In 1930, the writer witnessed the use of a charcoal fire preheat employed in welding the girth seams in 16 inch diameter copper tubes. The charcoal fire was inside the tube while the oxyacetylene welds were made from the outside.

In the case of welds in copper made by the carbon arc,* much higher concentrations of heat can be obtained and preheat with its inconvenience and undesirable expansion of the metal, can be avoided. Successful application of the carbon arc was delayed until 1933 because most of the welding generators available were designed for steel electrodes calling for moderate amperage and voltage. Hence, the high heats necessary for copper, about 440 amperes with a 40-volt arc for $^1/_4$ inch thick copper, were not available.

It should be noted that the high heat necessary for welding copper is required to overcome the high thermal conductivity of the *base metal*. No difficulty is occasioned by the thermal conductivity of the filler rod as the heat is, in this case, applied to such a small volume of metal.

The other difficulty which caused so much trouble to early copper weldmen was found to be occasioned by the small amount of oxygen, usually 0.03 to 0.07%, in tough pitch copper in the form of small specks of cuprous oxide scattered more or less uniformly throughout the volume of metal. This small amount of cuprous oxide does no harm to the copper when it is to be used for electrical or purposes other than heating or welding. In fact, it has a beneficial effect in keeping the grain size small.

But when the copper is to be welded, the cuprous oxide causes a weakness in the base metal a few thousandths of an inch back from the fusion zone. It causes trouble in several ways:

(*a*) It is reduced to copper and water vapor by the hydrogen which diffuses into the hot solid copper. The water vapor cannot diffuse outwardly. Hence, as Wyman[6] states, "the highly superheated steam literally blows the copper apart." This type of weakness cuts the welded strength to approximately 50% of the strength of the soft base metal.

(*b*) Porosity in the form of small spherical voids at the fusion line of a carbon arc weld in electrolytic copper may be occasioned in a somewhat similar manner, the carbon monoxide in the arc flame acting as the reducing agent taking oxygen from the cuprous oxide to form carbon dioxide. This type of porosity is in evidence in Fig. 15 though a higher magnification is needed to bring it out. This reducing action of carbon monoxide from the carbon arc flame undoubtedly accounts for some of the weakness noted in a slowly made carbon arc weld in tough pitch copper base metal.

(*c*) It is possible also that, as Le Grix[3] pointed out in 1922, the simple melting of tough pitch copper may cause a redistribution of the cuprous oxide at the fusion line to form copper-cuprous oxide eutectic with a weakening effect in this zone. We have not been able to demonstrate this effect in the studies thus far made.

The weaknesses described above are corrected by hot forging after welding. The Deutsches Institute[10] cites the case of an oxyacetylene weld in tough pitch copper using a silver bearing phosphorous, deoxidized copper welding rod, which, when tested "as-welded" showed an average strength of 17,050 pounds per square inch which was little more than 50% of the strength of the soft base metal. The elongation was only 6 to 9 %.

This same weld when hammered while hot shows a strength of 28,400 to 34,100 pounds per square inch with an elongation of 30 to 34%, which means an improvement in strength approaching 100% of that of the soft base metal with an improvement in ductility to nearly 80% of that of the unwelded base metal.

The thing of paramount importance to be noted in the above discussion is that the weakness is due to the cuprous oxide in the *base metal*. Hence, it cannot be corrected by any virtue in the welding rod.

## PLAN OF INVESTIGATION

In planning any investigation, it is always desirable to start with the known and then proceed to the unknown. The first part of this investigation, therefore, deals with the evaluation of the weldability of known alloys. This report is concerned principally therewith.

Referring to the *Welding Handbook*,[12] we note that besides the oxygen-bearing tough pitch copper *base metal*, phosphorous deoxidized copper and silicon deoxidized copper are listed as base metals.

For joining these base metals, the Handbook[12] lists nine different alloys. However, four of these, namely silver solder, spelter solder, yellow bronze and phosphor copper, are more in the nature of brazing solders applicable to scarfed or over-lapping surfaces while this paper is concerned only with fusion welds. Also, beryllium copper is regarded more as a facing metal for copper than as a welding rod which leaves for consideration only four general alloys, (*a*) deoxidized copper, (*b*) low tin phosphor bronze, (*c*) high tin phosphor bronze and (*d*) the silicon-manganese copper alloys.

* The carbon arc is used in preference to the metallic arc as the heat is limited in the latter case by the capacity of the melting wire. If the current is too high, the wire melts more rapidly than the base metal, making cold laps thereon. Moreover, there is too much "spatter" loss of weld-metal. In the use of the carbon electrode, there are no such limitations to the heat.

In addition to the five elements, i.e. oxygen, phosphorus, silicon, manganese and tin, which are used to make up the four general alloys applicable as fusion welding rods, there are a score of other elements which may be used with copper. The effect of all of these elements should be evaluated before we can say that we have arrived at the optimum welding alloy. And, when it is considered that these elements may be used singly with copper or two or more together, it is apparent that the work can become rather involved.

Another complication that makes the work rather expensive arises from the high thermal conductivity of the copper base metal. In order to make the welds at all comparable to commercial welds, it became necessary to use copper plates rather large and thick. This meant a considerable poundage of copper sheet.

We also desired to subject the metals to heat conditions as severe as any they would be likely to encounter in commercial work. Thus, a $^3/_8$ inch thick plate welded by the oxyacetylene torch in *one* pass is considered to be about the severest condition that a gas welding rod is likely to encounter while $^1/_4$ inch thick plate welded in *one* pass by the carbon arc is thought to be about the most severe heat condition that an arc-welding rod is likely to be called upon to endure.

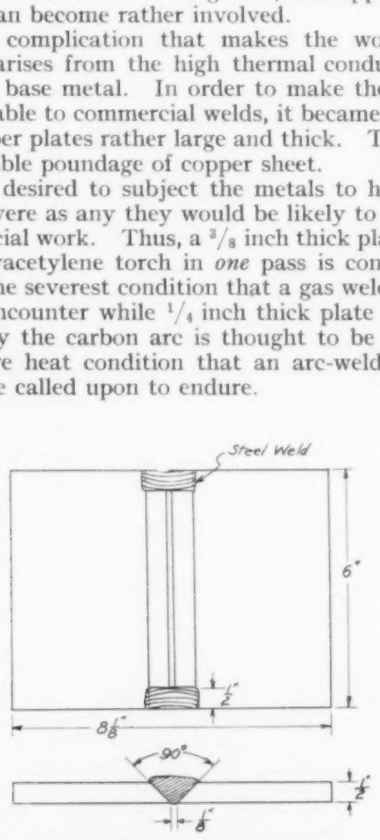



**Fig. 1—Steel Base Metal for Series 1 Welds**

Taking all of these things into consideration, we settled upon 8 x 12 x $^3/_8$ inch plates for the gas welds and 8 x 12 x $^1/_4$ inch plates for the carbon arc welds. Welded along the 12-inch edges, this made a 16 x 12 inch welded plate to be cut up for tests.

*Properties to Be Evaluated*

Not all of the properties of an alloy are involved in a weldability rating. Some of the more important ones are as follows:

(*a*) *Relative Melting Point.*—The absolute value is not significant but the relationship of the melting point of the welding rod to that of the base metal should be known. In general, it is desirable to have a welding rod melting at a slightly lower temperature than the base metal.

(*b*) *Strength.*—The weld-metal in the "as-welded" condition should have a slight margin of strength over that of the base metal in the annealed condition.

A primary aim of this investigation is to secure a welded seam that will have ample strength and ductility without recourse to after treatments such as hot or cold working, annealing, etc.

(*c*) *Ductility.*—The weld-metal in the "as-welded" condition should have a cold ductility comparable to that of the soft base metal. It should have good ductility at all temperatures up to the melting point.

(*d*) *Soundness.*—The weld-metal should be free of all types of unsoundness as hot short cracks, large and small gas pockets, shrinkage cavities, flux or oxide inclusions and cold laps.

(*e*) *Flowing Properties.*—This item includes relative fluidity (or viscosity) of the metal at welding temperatures, its "wetting" or "tinning" ability on the base metal, character of its surface when molten as viscosity and type of film, surface tension, response to fluxing, etc.

(*f*) *General Properties.*—Other properties of the weld-metal which should be evaluated are *color match, grain size, hardness, corrosion resistance* and *fatigue resistance.*

Thus, the color match, not usually important in copper welding, may be vitally important in a welded architectural shape.

Because of their effect on fatigue resistance and impact, large grains are undesirable. A grain growth inhibitor which acts, in this respect, like the cuprous oxide in tough-pitch copper, is desirable in the weld-metal.

Since so much of the welded copper goes into chemical equipment, the relative corrosion resistance of the weld-metal compared to that of the base metal is vital.

Also in developing a welding rod for copper, another very desirable feature would involve the use of the welding rod with equal facility in either gas or arc-welding operations. Most of the commercial welding rods obtainable for copper welding are satisfactory for one method of welding but not for both. For example, the high phosphorous copper welding rods which work advantageously in carbon arc welding are prone to show bad porosity and hot short cracks in gas welding. Similarly, the low phosphorous, silver bearing copper rods which make very good welds by the gas method are likely to yield weak welds badly oxidized on top when used with the arc.

The *base metal* cannot be pointed for weldability as freely as can the welding rod. Requirements for ultimate use must be given preference. For example, nothing can be done to reduce the thermal conductivity of the base metal though this property is the greatest single obstacle to the welding of copper. However, something can usually be done without impairing its usefulness for its ultimate service. Thus, adjustments may be made in minor constituents which offer promise of improved weldability with grain growth inhibiting better hot working properties, improved surface, im-

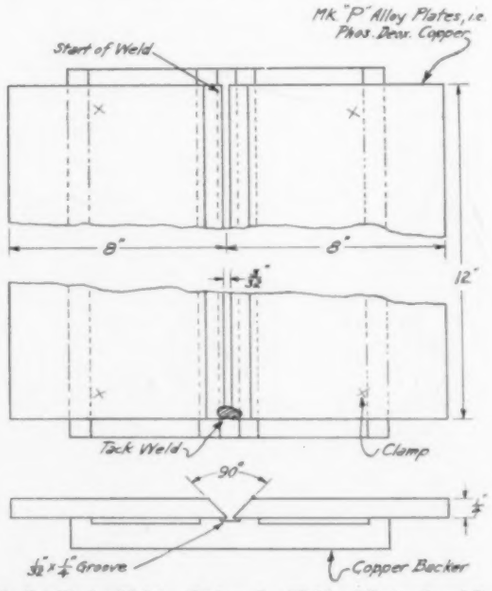



**Fig. 2—Set-Up for Making Carbon Arc Welds of Series 2 and Series 4**

proved resistance to corrosion and fatigue. The base metal can also be improved in strength but usually this results in an entirely different alloy.

## PLAN OF WELDS

The investigation could be confined to studies on the welding rods when being fused and small welds on thin copper. Geldbach[13] working along these lines gathered some excellent data on the welding of copper. However, as was stated before, it was our purpose to subject the metals to tests similar in character to commercial applications and of a severity comparable to the maximum it is likely to receive when so used.

For this purpose seven series of welds were planned, the aim being to eliminate as quickly as possible all alloys showing little promise as welding rods, thus:

Series 1 is a weld designed to bring out the hot and cold ductility of the alloy as disclosed in a rigid oxyacetylene weld.

Series 2 is intended to show up the flowing properties, the hot and cold ductility and soundness of the welding rod as disclosed in a single pass carbon arc weld.

Series 3 is a free, single pass oxyacetylene weld in $^3/_8$-inch thick copper in which the flowing properties, the strength, ductility and soundness are determined.

**Table 1—Copper Alloy Rod Deposited on Steel Plate by Oxyacetylene Flame-Effect on Constituents**

| Mark | Sample from | Composition, % Copper | Iron | Oxygen | Sulphur | Remarks |
|---|---|---|---|---|---|---|
| *G* | Rod | Rem. | ... | 0.020 | 0.0021 | Electrolytic |
| " | Weld | " | ... | 0.008 | 0.0025 | copper |
| | | | | Phos. | | |
| *B* | Rod | " | 0.009 | 0.084 | .... | Phosphorous de- |
| " | Weld | " | 0.296 | 0.068 | .... | oxidized copper |
| *C* | Rod | "* | 0.002 | 0.086 | .... | Silver bearing, de- |
| " | Weld | " | 0.184 | 0.079 | .... | oxidized copper |
| | | | | | Tin | |
| *F* | Rod | " | 0.000 | 0.028 | 1.70 | Low tin phosphor |
| " | Weld | " | 0.154 | 0.018 | 1.73 | bronze |
| *K* | Rod | " | ... | 0.348 | 4.44 | Grade A phosphor |
| " | Weld | " | ... | 0.280 | 3.79 | bronze |
| | | | | Silicon | | |
| *A* | Rod | " | 0.001 | 0.06 | ... | Silicon deoxidized |
| " | Weld | " | 0.103 | 0.04 | ... | copper |

* Includes 1.02% silver.

Series 4 is similar to Series 3 except that the copper is only $^1/_4$ inch thick and the weld is run with the carbon arc. The weld is run in the same manner as are the welds of Series 2 but the method of testing and inspection are different.

Several additional series, not complete at this writing will be run on various $^1/_8$ inch thick samples of base metal alloys and on 8 x 12 inch plates of the optimum base metal alloy and welding rod alloy, thus giving the materials a final test before offering same for commercial service.

## SERIES 1 WELDS

As was stated above, this weld was planned as a severe test on the hot ductility of the welding rod alloy. Owing to the low elastic limit and strength of copper at temperatures close to its melting point, copper base metal could not be used. It would be insufficiently rigid to the solidifying and cooling copper filler metal. In this series, therefore, *steel* was used as the base metal with the plates arranged as illustrated in Fig. 1.

It will be noted that the welds of Series 1 are 90° single vee butt welds 5 inches long with the $^1/_2$-inch steel plates held rigidly apart by the $^1/_2$ inch of steel butt welds at either end of the vee. The plates were also rigidly clamped to steel channels to restrain the shrinkage stresses in the copper alloy weld-metal from bowing the plates.

The 5-inch length of weld, coupled with the extremely rigid disposition of the plates, made a very severe test on the filler metal for hot ductility. If it were the least bit inclined to be hot short in any temperature range from black heat to its melting point, hot short areas would be developed.

The action of the copper filler metal on the steel was in the nature of a surface alloying or brazing. The steel was not appreciably melted but was brought up to a bright red heat at which temperature most of the molten copper alloys "wetted" it greedily and a strong bond was obtained.

All of Series 1 welds were made by the oxyacetylene blowpipe. It is believed that the slower action and wider spread of heat of this method of welding (as compared to arc welding) adds to the severity of the test.

It may be asked whether the iron pick up was not likely to vitiate the test. In order to note how serious this was, samples were taken from the top middle third of the weld and compared with original welding rod. The changes in other elements due to the melting by the oxyacetylene flame were also determined and given below in Table 1.

Judging from the above, the average increase in the iron due to dissolving same from the beveled sides of the steel plate is approximately 0.16% of the alloy base. This, it will be noted, is in the region of the weld most affected by shrinkage stresses, i.e. the top third. Since Hanson & Ford[14] had no difficulty in working copper containing iron up to 1%, we believe it is fair to assume that 0.16%, or even the 0.296% of Rod *B*, will not occasion serious hot shortness in copper or mask the hot shortness due to phosphorus. One might suppose that, if the iron combines chemically with a hot short agent such as phosphorus,[16] the effect of the latter would be ameliorated. This is, however, not the case.

The values of Table 1 show other interesting results due to the melting operation with the oxyacetylene torch. Thus, in the tough-pitch copper of Rod *G*, the oxygen is reduced from 0.020 to 0.008% by the effect of the torch gases. This reducing action of the oxyacetylene flame has long been known.[15]

The high temperature of the oxyacetylene flame causes a reduction in the phosphorus of about one-third and nearly the same loss or slightly less of silicon. The phosphorus evaporates from the melt and the silicon oxidizes, the resulting oxide melting and forming a thin continuous liquid film over the melt.

Though the oxyacetylene flame is reducing to cuprous oxide, it nevertheless will oxidize silicon or phosphorus which have a very high affinity for oxygen. Thus, while the hydrogen and carbon monoxide are reducing to cuprous oxide, the water vapor and carbon dioxide are oxidizing to the silicon and phosphorus.

*Tests of Series 1 Welds.*—The only physical test given the Series 1 welds was a face bend and an inspection of the fracture. The $^1/_2$-inch tack welds of steel at either end of the plates being made with bare metallic arc electrodes, were low in ductility and broke with but little bending. The results of the tests are given in Table 2.

*Remarks on Results in Table 2.*—In interpreting the results of Table 2, it should be understood that the welds of Series 1 constituted an unusually severe test on the

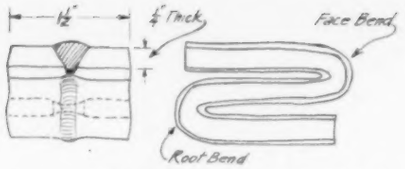



Fig. 3—Transverse Flat Back Bends on Seam of Series 2 Welds

**Table 2—Face Bend Tests on Series 1 Welds**

| Mark | Welding Rod: Copper | Oxygen | Iron | Bend at Failure Degrees | Hot Short Area, % | Voids % | Sound Metal % |
|---|---|---|---|---|---|---|---|
| *G* | Rem. | 0.020 | ... | 30 | 40 | 40 | 20 |
| | | Phosphorus | | | | | |
| *BB* | Rem. | 0.032 | ... | 1 | 95 | 4 | 1 |
| *B* | " | 0.084 | 0.009 | 1 | 99 | .. | 1 |
| | | Silicon | | | | | |
| *A* | " | 0.063 | ... | 70 | 3 | 15 | 82 |
| *X* | " | 0.25 | ... | 45 | .. | 20 | 80 |
| | | Phosphorus | Tin | | | | |
| *F* | " | 0.03 | 1.69 | 40 | 35 | .. | 65 |
| *FF* | " | 0.20 | 2.75 | .. | .. | .. | .. |
| | | | Silver | | | | |
| *C* | " | 0.088 | 1.02 | 30 | 35 | .. | 65 |
| | | | Tin | | | | |
| *K* | Rem. | 0.37 | 4.41 | Pulled away from steel | | | |
| *L* | " | 0.33 | 10.29 | .. | .. | .. | .. |
| | | Silicon | Manganese | | | | |
| *M* | " | 3.10 | 1.08 | .. | .. | .. | .. |

hot ductility of the metal. An alloy which would show a hot short area covering 95% of the fracture could still be used for welding where the plates were free to come and go. Or it might be successfully used where the welding action is extremely rapid as in some carbon arc welds. None of the alloys was condemned on the basis of Series 1 welds alone.

Since for the most part only one test was made on each alloy, no close comparisons can be made of the results. In a broad interpretation, however, the results do have some significance. Thus:

*Electrolytic Copper, Mark G.*—The tests show that with 40% of the area showing a hot short fracture, the metal must be lacking in ductility at some point in the welding temperature range. On the other hand, the 30° bend before failure (obtained by matching the broken halves and reading the angle) indicates good cold ductility. Especially is this true when the notch effect of the hot short areas and the porosity is considered. The high area of voids, 40%, indicates bad gas action on this metal.

*Effect of Phosphorus, Alloys B, BB, F and C.*—It seems clear that phosphorus is responsible for extremely bad hot short cracks which in turn result in a negligible cold ductility of the weld as measured by the bend. Even with phosphorus as low as 0.032% in Alloy *BB*, it appears to show a very bad effect on the hot ductility. Owing to the high area of hot short fracture, little is indicated as to the gas effect on the alloy.

Alloy *C* appears to be somewhat less hot short than the other phosphorous alloys which may be due to an ameliorating effect of the 1.02% of *silver*. Tin does not appear to neutralize the hot short reaction of phosphorus.

*Effect of Silicon, Alloys A and X.*—Silicon deoxidized copper shows a decided improvement in hot ductility over phosphorous deoxidized copper. This fact was recognized by S. W. Miller[4] in 1926. It also contributes to the soundness of the metal. The writer ascribes the last named effect to the fact that the weld pool is covered with an impervious liquid silica glass film which protects the molten metal from actual contact with the hot gases. This film forms as the metal is melted.

## SERIES 2 WELDS

In carbon arc welding, the heat liberated is a function of $EI$ where $E$ is the voltage drop across the arc and $I$ is the current in amperes. Within certain limits, depending upon the characteristics of the welding generator, a given heat value may be obtained by rather wide variations in arc voltage (arc length) and arc current. Thus, 200 amperes flowing in a 20-volt arc (short arc) represents the same amount of heat that would be liberated by only 67 amperes passing a 60-volt arc (long arc). The effect of these two arcs on a given metal, however, would be quite different. The heat would be more localized and the temperature of the weld pool higher in the 200 amperes, short arc than in the 67 amperes, long arc.

Generally speaking, if the metal will endure the high temperature without suffering damage, the short arc and restricted weld pool is preferred to a long arc with its greater tendency to wander and its wider spread. Also the short arc lends itself more readily to position welding. However, some metals will work quite satisfactorily with one type of the arc and not with the other. In working with new alloys for welding rod and base metals and different thicknesses, it is necessary to determine by actual trial the current value and arc length that will yield the soundest, toughest weld-metal with the correct penetration. Series 2 welds were made with this object in view.

Figure 2 shows the dimensions and set-up for the making of Series 2 welds by the carbon arc. The 8 inches on either side of the weld is regarded as being close to the minimum to obtain thermal conductivity effects comparable to the effect of a commercial sheet. Also the 12-inch length of weld approximates the minimum length and time interval that is needed to secure stable conditions and satisfactory readings. In general, the time required to run the 12 inches is from 60 to 90 seconds. The $^1/_4$ inch is close to the maximum thickness of copper that it is desirable to be run in one pass.

Aside from the readings and observations made during the run of the weld, an examination of the weld-metal was made to determine the effect of the arc heat on it.

The welds were sheared out of the sheets by cutting along lines $^3/_4$ inch to either side of the weld axis. Bends were made as indicated in Fig. 3. Also, since we were interested in the weld-metal only, all of the welds were run on a single base metal—phosphorous deoxidized copper. The deoxidized copper was used in preference to electrolytic copper base metal as there is always a weakness in the latter adjacent to the weld. The results of Series 2 welds are given in Table 3.

The Series 2 welds were made with the direct current carbon arc, the negative electrode being a $^1/_2$ inch diameter high capacity graphite.

Samples were taken for analysis from the top middle third of the weld in order to determine what had happened to the metal as it was melted by the extremely hot arc of Series 2, i.e. 400 to 500 amperes. As the base metal was phosphorous deoxidized copper carrying 0.02 to 0.035% phosphorus, there would be some dilution of the weld-metal from the base copper. Hence, the analysis of the weld-metal would show a greater apparent loss of the deoxidizers and other added elements than is actually the case. However, the following results of Table 4 are interesting and enlightening.

*Effect of Arc on Phosphorus.*—A study of alloys *B*, *C*, *F*, *K* and *L* show (*a*) that with phosphorous proportions varying from 0.017% of Alloy *F* to the 0.080% of Alloy

*C*, there is, even with the longest possible arc, severe burning of the metal which is exposed directly to the arc blaze.

Figure 4 illustrates this condition. The metal in the top of the weld which has received the full benefit of the arc is badly porous and oxidized. At this section, it is very unsound for a depth of approximately 0.08 inch. Clearly the 0.069% phosphorus of the original welding rod was insufficient to keep all of the metal completely

**Table 3—Transverse Flat Back Tests on Series 2 Carbon Arc Welds**

| Welding Rod | Welding Data Amps. | Volts | Speed* | Observations, Bend Tests, Remarks and Conclusions |
|---|---|---|---|---|
| Flowed about the same as *B*. Very fluid. | | | | |
| *BB* | 500 | 51 | 21 | At 90° the face showed short cracks while the root bend was O. K. At 180°, both face and root showed small cracks. At flat back, the face showed one large crack and numerous small ones while the root showed several wide cracks and small cracks with porosity. Cracks start at hot short checks. In general, the phosphorous deoxidized copper shows evidence of hot shortness no matter how low the phosphorus content—the 0.032% phosphorus of Alloy *BB* being close to the commercial minimum. The 0.032% phosphorous alloy shows slightly better ductility than the 0.084% phosphorous alloy. |
| Flowed freely with clear pool, gentle agitation of surface. A shorter arc increases the agitation which is probably caused by the evaporation of the phosphorus. | | | | |
| *B* | 490 | 55 | 14 | At 90° both root and face showed slight cracks. At 180°, numerous cracks in root and face. At flat back, one large crack developed in face with numerous fine cracks near edge. Porous at top, dendritic at center. Occasional large blowholes. The root showed one wide crack with considerable porosity. Small hot short cracks in bottom of weld. The lower heat range gave imperfect penetration. The expansion of the top caused hot short fractures at the root. |
| Flows quietly, very fluid, clear pool, less danger of undercutting than with the phosphorous coppers. | | | | |
| *A* | 500 | 45 | 16 | At 90°, the face bend showed a crack opening up at a gas pocket. The root was O. K. at 90°. At 180° the face showed a wide crack and the root an incipient crack. At flat back, the face showed a wide crack and porous metal with only a slight crack at the root. This alloy appears to have better hot ductility than the phorphorous deoxidized copper. |
| Flows quietly with good penetration. Open channel down center of bead due to refractory oxide following the arc. | | | | |
| *X* | 490 | 45 | 13.5 | At 90° to 180°, the face showed porosity in the middle of the bead and numerous short cracks while the root was O. K. at 180° except for poor fusion on one side. At the flat back, the face showed one wide crack and several irregular cracks and large gas pockets while the root showed one wide crack and a large gas pocket. The weld-metal is very coarse grained. |

**Table 3** (*Continued*)

| Welding Rod | Welding Data Amps. | Volts | Speed* | Observations, Bend Tests, Remarks and Conclusions |
|---|---|---|---|---|
| Flows sluggishly. Appears burnt on top. Imperfect penetration. | | | | |
| *F* | 425 | 47 | 12 | At 90° the face showed a wide crack with the root O. K. At 180° the face showed two wide cracks and many small ones with the root still O. K. The flat back showed bad porosity on top and small cracks on root bend. |
| *C* | 490 | 47 | 15 | Fair flowing about same as *BB*. At 90° the face was O. K. with several slight cracks at the root. At 180° the face developed several slight cracks also starting at the root. At the flat back there were numerous cracks at the face with moderate porosity and at the root wide cracks with occasional gas pocket. |
| Penetration not quite as good as with sample *L*. Top looks more burnt than is the case with sample *L* though actually subjected to less heat than the latter. | | | | |
| *K* | 420 | 52 | 12 | Face and root bends O. K. at 90°. Face bend still O. K. at 180° but crack starting in root. At the flat back, a narrow crack showed in the face with the metal quite sound with a slight crack in the root and a large gas pocket showing. |
| Good flowing metal. Good penetration. | | | | |
| *L* | 450 | 52 | 6 | Both face and root bends O. K. at 90°. Face still O. K. at 180° with slight crack starting at root. At the flat back, the face showed a few narrow cracks with very sound metal while the root showed two small cracks and several gas pockets. |
| Flows good with good penetration. Withstands without damage an extremely high heat and short arc. | | | | |
| *M* | 510 | 41 | .. | Face and root bends O. K. at 90° and at 180°. At the flat back the root was O. K. with no cracks developing in the face though there was a slight porosity. |

* Inches per minute.

**Table 4—Changes in Composition Due to Action of 450 ± Amperes Carbon Arc**

| Alloy | Analysis | Composition, % Copper | Phosphorus | Silicon | Silver | Remarks |
|---|---|---|---|---|---|---|
| *B* | Rod | 99.926 | 0.069 | ... | ... | Phosphorous deoxidized copper |
| | Weld | 99.820 | 0.015 | ... | ... | |
| *A* | Rod | 99.932 | ... | 0.056 | ... | Silicon deoxidized copper |
| | Weld | 99.912 | ... | 0.014 | | |
| *C* | Rod | 99.840 | 0.080 | ... | 1.030 | Silver - bearing phosphorous deoxidized copper |
| | Weld | 99.251 | 0.019 | ... | 0.691 | |
| | | | | | Tin | |
| *F* | Rod | 98.152 | 0.017 | ... | 1.751 | High conductivity phosphor bronze |
| | Weld | 98.662 | 0.006 | ... | 0.389* | |
| *K* | Rod | 94.900 | 0.310 | ... | 4.855 | Grade A phosphor bronze |
| | Weld | 97.044 | 0.128 | ... | 2.963 | |
| *L* | Rod | 89.354 | 0.285 | ... | 9.984 | Grade D phosphor bronze |
| | Weld | 93.146 | 0.134 | ... | 6.709 | |
| | | | | Manganese | | |
| *M* | Rod | 95.698 | ... | 3.098 | 1.083 | Silicon manganese bronze |
| | Weld | 97.653 | ... | 1.675 | 0.591 | |

* Also 1.008% tin oxide.

Fig. 4—Macro-Photograph 5X of Weld Made with Alloy *B* Rod on 1/4-Inch Thick Phosphorous Deoxidized Plate (Table 3)

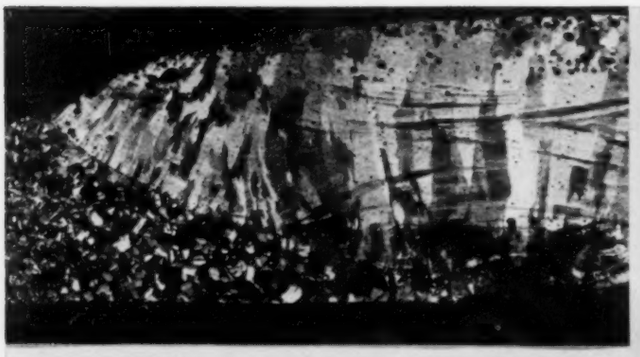
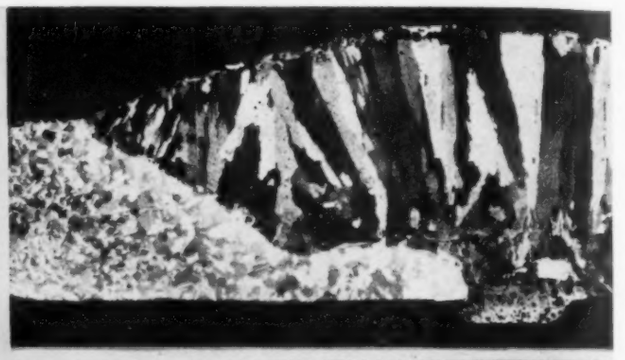


Fig. 5—Weld on 1/4-Inch Thick Phosphorous Deoxidized Copper Made with Alloy *L*, Table 4. Note General Soundness of the Metal Except for Extreme Bottom and Top Surfaces



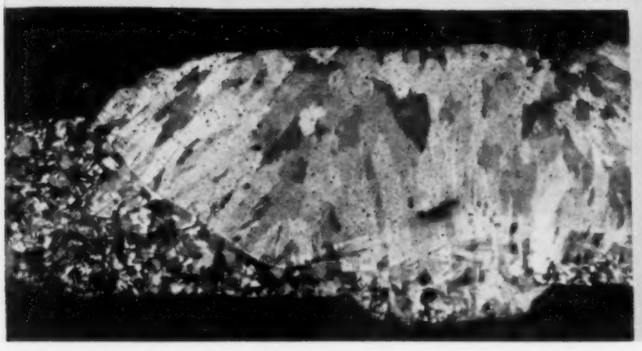


Fig. 6—Arc Weld (Tables 3 and 4) of Alloy *A* Rod on 1/4-Inch Deoxidized Copper Plate

Fig. 7—Arc Weld of Alloy *M* (Table 4 Only) on 1/4-Inch Deoxidized Copper Plate

deoxidized. This fact is brought out even more sharply in the analyses of the weld made with Alloy *F* which was run at 12 inches per minute with an average closed circuit current and voltage of 425 amperes and 50 volts. It will be noted from Table 4 that more than half of the tin was oxidized and the heavy (Sp.g. about 6.9) tin oxide entrapped in the weld-metal.

Contrasted with Alloys *B* and *F* having low phosphorus, we have alloys *K* and *L* with phosphorous contents of 0.310% and 0.285%, respectively. Alloys *K* and *L* made very good welds on 1/4-inch phosphorous deoxidized copper plates. The face and root bends showed, in general, better ductility and sounder weld-metal than did welds made with Alloys *B* and *F*. The weld of Alloy *L* was run at the rate of only 6 inches per minute though the current was 450 amperes with an arc voltage of 52. Hence, the metal received even more severe heat conditions than did that of Alloy *F*.

A careful check with the microscope and analytical methods showed no appreciable amount of tin oxide or cuprous oxide. It seems apparent that the higher phosphorous content of Alloys *K* and *L* was sufficient to keep the metal deoxidized under the most severe welding conditions.

Evidently 0.25% phosphorus is sufficient to keep the copper and tin deoxidized under severe arc-welding conditions while 0.08% is not.

*Effect of Arc on Silicon.*—Phosphorus evaporates from the weld pool as a gas exerting a strong reducing action on the surface. Silicon on the other hand oxidizes and combines with other metallic oxides to form a liquid glass film over the weld pool. This film protects the metal underneath from the arc atmosphere so that a much shorter arc can be used with a silicon deoxidized copper than is the case with a phosphorous deoxidized copper. This film should also be effective in preventing in some measure the contact of the molten weld-metal with the hot gases thus contributing to its soundness.

The weld sections shown in Fig. 6 (low silicon) and Fig. 7 (high silicon) are, in general, quite sound. The low silicon weld-metal of Fig. 6 appears noticeably sounder than the low phosphorous weld-metal of Fig. 4 but less so than that of the high phosphorous alloy, Fig. 5, or the high silicon of Fig. 7.

The weld-metal of Fig. 7 deposited with the extremely hot arc of 510 amperes at 44 volts closed circuit was unusually ductile taking a full flat back bend in both face and root bend samples.

Silicon as well as phosphorus shows a decided loss in its proportion as a result of its being melted by the arc. However, since the base metal contained no silicon, the dilution of the weld-metal would be greater in the case of the silicon rod than in the case of the phosphorous rod.

The phosphorus appears to evaporate as long as the weld pool is kept at a superheat by the play of the arc. The observed simmering of the surface appears to indicate this. The silicon film, on the other hand, does not build up appreciably in thickness in a given arc superheat. A reasonable conclusion appears to be that the silicon loss in an arc weld is somewhat less than the phosphorous loss under the same conditions.

*Effect of Arc on Silver and Tin.*—It appears obvious that silver and tin need the presence of an active deoxidizer as much as copper itself. In fact, the tin oxidizes at these high superheats more readily than the copper. This is shown by the analysis of the Alloy *F* weld-metal reported in Table 4. Moreover, the tin oxide is particularly objectionable—it is too heavy to be easily floated out of the melt. Silver oxide, though having a high specific density, is not particularly troublesome as it is unstable at the temperatures within the melt, forming only on the surface as the metal cools down.

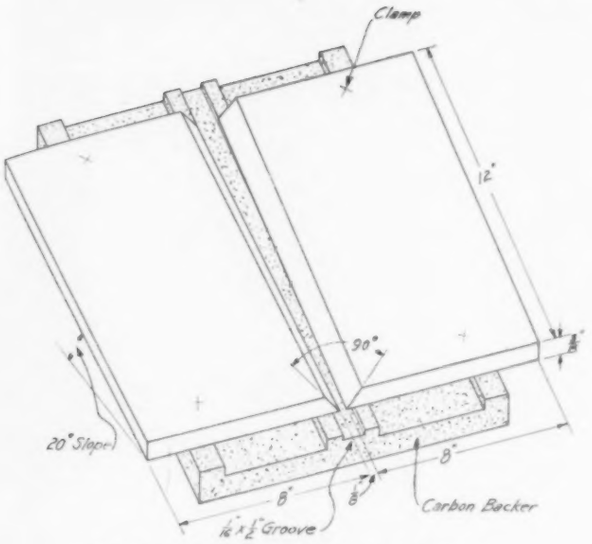



Fig. 8—Set-Up for Series 3 Oxyacetylene Weld

## SERIES 3 WELDS

In planning this series, several questions were considered. For example, what was the maximum thickness for a single pass weld? A single pass weld was desired as this is the weld most frequently made. Moreover, a multiple pass weld is complicated by variable heat and strain effects on the first pass which are difficult to evaluate. On the other hand, thick plates were desired in order to subject the weld-metal to the most severe heat conditions it is likely to encounter. 3/8-inch thick plates were selected as these proved to be on trial about the *maximum* thickness that could be welded with a single-flame torch in the absence of other preheat.

Another question dealt with the *minimum* width and length of plates. With a 3/8-inch thickness, the weight of metal and the costs run up rather rapidly with increasing size. On the other hand, if the plates were too narrow, the metal would become too hot at the finish end, unless the torch head were changed in the middle of the weld. An eight-inch width on either side of the weld was found to be close to a minimum to secure uniform heat conditions along a 12-inch weld. The 12-inch length of weld was needed to secure the requisite number of samples for full section tensile, reduced section tensile, face bend, root bend and micro-sample with a reasonable discard at either end.

A third question concerned the type of backer (or no backer) to use. Owing to the high heat and nearly flat position some type of backer was imperative. Thin copper could not be used as it would melt through and thick copper was undesirable on account of its high heat absorption. Steel was not wanted as the copper weld-metal would stick to it. Asbestos sheet could be used but we preferred a grooved carbon plate which could be used over and over though its heat capacity was markedly higher than that of asbestos. The carbon backer was relieved in order to minimize its robbing the plates of their heat. The set-up is illustrated in Fig. 8.

*Flux.*—The copper welding rods deoxidized with phosphorus did not require a flux. The phosphorus as it evaporates from the melt keeps the surface deoxidized and bright, the resulting phosphorous oxide escaping as a gas. The silicon deoxidized welding rods did, however, require a flux to thin and soften (but not completely dissolve) the silica glass film. Hence, to treat all rods alike, we used flux on *all* rods, phosphorus included. We used commercial brazing flux made up of fused borax and boric acid. The flux was mixed with hot water and painted on the base metal while the rods were prefluxed by preheating same and running them through a pile of dry flux.

The welding rods were all approximately 1/4-inch diameter.

The *blowpipe* was used with a No. 12 head which in normal operation using oxygen at 20 pounds per square inch pressure with torch valve wide open and four pounds of acetylene throttled at the torch to give a neutral flame is rated at about 55 cubic feet per hour of acetylene and the same amount of oxygen.

**Table 5—Copper Base Metal of Series 2, 3 & 4 Welds**

| Mark | Composition, % Copper | Oxygen | Thickness of Plate | Tensile Strength, Psi | Elongation in 2 Inches, % |
|---|---|---|---|---|---|
| Electrolytic copper. The oxygen as specks of cuprous oxide, uniformly distributed. | | | | | |
| *E* | Rem. | 0.031 | 1/4 | 31,900 | 58.3 |
| " | " | 0.031 | 3/8 | 31,700 | 60.5 |
| Phosphorous deoxidized copper. | | | | | |
| | | Phos. | | | |
| *P* | Rem. | 0.023 to 0.036 | 1/4 | 33,350 | 59.8 |
| " | " | " | 3/8 | 32,200 | 66.5 |
| Silicon deoxidized copper. | | | | | |
| | | Silicon | | | |
| *S* | Rem. | 0.049 to 0.064 | 1/4 | 33,300 | 59.5 |
| " | " | " | 3/8 | 32,600 | 63.0 |

This, however, furnished insufficient heat for our purpose and for Series 3 welds, the oxygen pressure was stepped up to 36 pounds per square inch with the torch valve wide open and the acetylene at 5 pounds per square inch throttled at the torch to yield a neutral flame. This pressure gave a very sharp, hot blast but since most of the welding was down-hand, it offered no difficulty.

The plates were *preheated* from 3 to 5 minutes with the above blowpipe before actually starting the weld.

The welds were completed at the rate of 0.75 to 1.25 inches per minute with a weighted average of approximately 0.85 inch per minute or 14 minutes per foot of weld.

*Testing the Series 3 Welds.*—Bending tests, tensile tests and micro-examination were made on each of the Series 3 welds. Unlike the bends of Series 2, the bend tests of

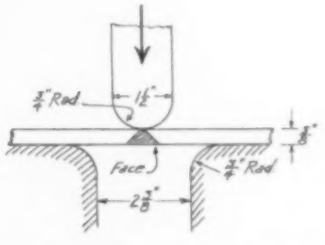



Fig. 9—Fixture for Making Face and Root Bends of Series 3 Welds

Fig. 9(a)—Flat Back Face Bend Test of Series 3 Welds

Series 3 were made with the axis of the bend coincident with the axis of the weld as illustrated in Fig. 9. The specimens, about $1^1/_2$ inch wide cut from the weld, were machined flush on top and bottom and forced into the bending jig of Fig. 9 until given a 180° bend. The face bend would be a sample bent with the top or face of the weld on the outside while the root bend would be on another sample having the bottom of the weld on the outside. After being bent 180° the samples were pressed flat as illustrated in Fig. 9(*a*).

The tensile specimens were also machined flush on top and bottom.

*Base Metal, Series 3 Welds.*—All of the material used for Series 3 welds was hot rolled to $^3/_8$ inch thick and annealed. Three different base metals were used, the compositions of which are given in Table 5. Only the most

**Table 6—Tensile and Bend Test Results of Series 3 Welds***

| Mark Base and Rod | Tensile Strength, PSI | Elongation in 2 Inches, % | Fracture, Remarks | Bend Tests | | | |
|---|---|---|---|---|---|---|---|
| | | | | Outside of Bend | 180° at 0.75 "Rad. | Flat Back | Elongation in $^1/_2$ Inch, % |
| *E-BB* | 16,330 | 10.3 | Along bevel, unsound 5% hot short | Face: | O.K. | *F* | 50 |
| | | | | Root: | F 80° | " | 42 |
| *P-BB* | 22,200 | 19.3 | In weld, slightly unsound and hot short | Face: | O.K. | " | 24 |
| | | | | Root: | " | " | 32 |
| *S-BB* | 26,870 | 30.0 | In weld, 1% hot short 2% cold laps | Face: | O.K. | *C* | 52 |
| | | | | Root: | " | " | 40 |
| *P-B* | 25,570 | 23.8 | In weld, unsound and 3% hot short | Face: | " | " | 44 |
| | | | | Root: | " | " | 44 |
| *E-A* | 15,530 | 8.5 | Along bevel, unsound | Face: | Fails at edge | *F* | 28 |
| | | | | Root: | Fails at 60° | " | 16 |
| *P-A* | 26,100 | 31.8 | In weld | Face: | O.K. | O.K. | 40 |
| | | | | Root: | " | " | 46 |
| *S-A* | 26,370 | 31.5 | In weld, coarse grained | Face: | " | " | 60 |
| | | | | Root: | " | *C* | 58 |
| *E-X* | 18,370 | 11.8 | Along bevel, unsound | Face: | Fails at edge | *F* | 42 |
| | | | | Root: | Fails at 45° | " | 20 |
| *P-X* | 28,370 | 36.7 | In weld, cold laps | Face: | O.K. | O.K. | 60 |
| | | | | Root: | Slightly cracked | | 64 |
| *E-F* | 15,800 | 8.5 | Along bevel and in weld. Unsound and cold lap | Face: | Failed at 100° | .. | 18 |
| | | | | Root: | Failed at 80° | .. | 12 |
| *P-F* | 22,570 | 18.2 | In weld, unsound | Face: | *C* | *F* | 20 |
| | | | | Root: | Failed at 80° | " | 6 |
| *S-F* | 31,670 | 47.2 | In weld, slightly porous | Face: | O.K. | O.K. | 48 |
| | | | | Root: | Failed at 90° | .. | 20 |
| *E-C* | 16,730 | 10.5 | Along bevel, unsound | Face: | *C* | *F* | 24 |
| | | | | Root: | Fails at 70° | " | 16 |
| *P-C* | 23,470 | 18.3 | In weld, slightly unsound | Face: | *C* | " | 20 |
| | | | | Root: | " | " | 30 |
| *S-C* | 25,800 | 29.8 | In weld, slightly unsound and hot short | Face: | O.K. | O.K. | 48 |
| | | | | Root: | " | " | 52 |
| *E-K* | 17,300 | 5.8 | At edge of weld. Very unsound. Also hot short areas | Face: | Failed at 90° | .. | 32 |
| | | | | Root: | Failed at 45° | .. | 14 |
| *P-K* | 24,100 | 21 | In weld, large blow-holes and cold laps | Face: | Slight cracks | *F* | 40 |
| | | | | Root: | " " | " | 32 |
| *P-L* | 24,200 | 14.3 | In weld, blow-holes | Face: | " " | " | 32 |
| | | | | Root: | Failed at 60° | .. | 20 |
| *E-M* | 20,830 | 9.0 | Edge of weld | Face: | Failed at 90° | .. | 40 |
| | | | | Root: | Failed at 80° | .. | 28 |
| *P-M* | 31,130 | 47.3 | In base metal | Face: | O.K. | O.K. | 54 |
| | | | | Root: | " | " | 48 |
| *S-M* | 31,730 | 47.5 | In base metal | Face: | " | Slight cracks | 56 |
| | | | | Root: | " | O.K. | 44 |

* Explanation of abbreviations used in Table 6: Under "Mark," column 1, the first *E*, *P* or *S* refers to the base metal of Table 5 and the second letter or letters refer to the welding rod identification from Table 2. *h.s.* = area cracked while hot, expressed in per cent of total area of fracture. *c.l.* = cold lap, per cent of total fracture. *b.h.* = blow-holes, per cent of total area of fracture. *F* = Failed. *C* = Cracked.

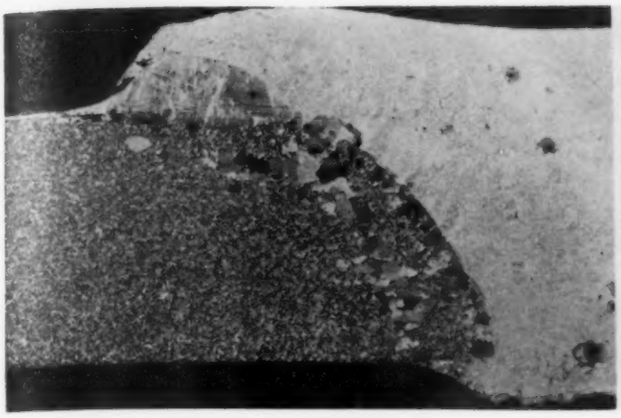


Fig. 10—Zone of Fusion in Weld, Mark *E-M*, Between Electrolytic Copper Base Metal and Silicon Manganese Bronze Weld-Metal. 5 X

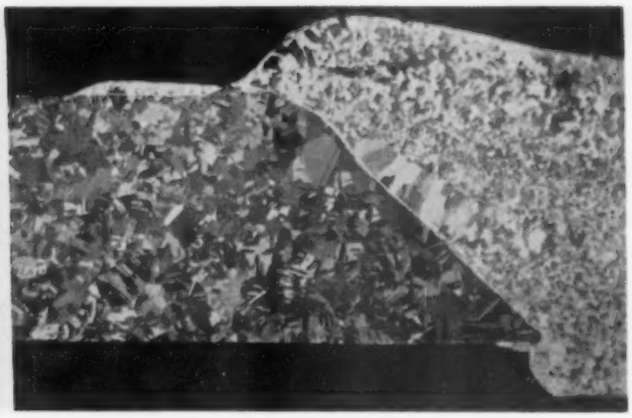


Fig. 12—Fusion Line Between Phosphorous Deoxidized Base Metal, Mark *P*, and Silicon Manganese Bronze Weld-Metal, Mark *M*. 5 X. Note 100% Soundness of Base Metal to Fusion Line

promising of the welding rod alloys were applied as filler rods to *all three* base alloys. Where a test was desired on a rod which showed up unsatisfactory in Series 1 and 2 welds, it was used on the phosphorous deoxidized copper base metal only.

The results of the tests on Series 3 welds are given in Table 6. The values for tensile strength and elongation in 2 inches are the averages of three tests on a given weld. Each specimen was approximately $^3/_8$ x 1 inch in section. Only one face bend and one root bend was made on each weld. The elongation in $^1/_2$ inch of the bend test was that of the outside fiber of the bend.

## DISCUSSION OF SERIES 3 WELDS

In reviewing the results of Series 3 welds given in Table 6, we note first of all that the highest strength obtained on electrolytic copper, Mark *E*, is that obtained with welding rod *M*. This compares very unfavorably with results obtained on the phosporous deoxidized base metal, Mark *P*, and on the silicon deoxidized plates, Mark *S*.

This weakness in the tough-pitch copper, Mark *E*, as explained in an opening paragraph is clearly due to hydrogen embrittlement of the base metal in the area within 0.025 inch of the fusion line, Fig. 10. It can be corrected only by hot forging of the weld or, in relatively thin metal, by cold peening of the weld followed by an anneal. This zone of weakness is clearly shown in Fig. 10 and in the higher magnification of Fig. 11. This weld after the reinforcement was machined off had an average strength of only 20,830 pounds per square inch, the failure taking place in the gassed base metal along the fusion line.

If no after treatment is to be used, the only way in which the strength in tough-pitch copper can be improved is by the use of a wider angle or shear vee which increases the area of fusion and, therefore, of contact with the strong weld-metal. The *M* weld-metal has a gas-welded strength of 50,000 pounds per square inch or better.

Fig. 11—Line of Fusion in Weld, Mark *E-M*, Between Electrolytic Copper Base Metal, *E*, and Silicon Manganese Bronze, *M*. 75 X

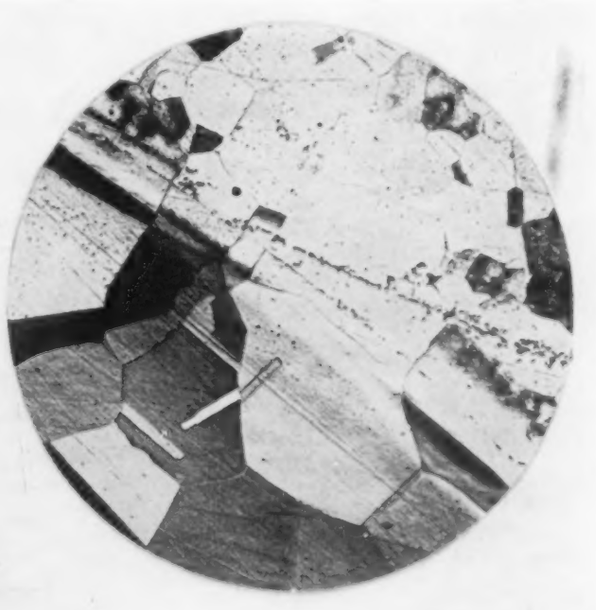


Fig. 13—Fusion Line Between Phosphorous Deoxidized Base Metal, *P*, and the Silicon-Manganese Bronze Weld-Metal, *M*. 75 X. Note 100% Soundness of the Base Metal to the Fusion Line

Another interesting point is brought out in Fig. 10. In a zone approximately 0.05 inch wide, about 0.10 inch back from the fusion line, the temperature and time conditions were such as to cause a recrystallization of the solid base metal to form very large grains of the order of *0.800* mm. or a grain growth approximately *12* times that of the original metal. A closer inspection of this area shows the cuprous oxide to be more or less uniformly scattered in these large grains as it is in the original metal. There was no evidence of the formation of the copper-cuprous oxide eutectic as described by Le Grix.[3]

A much more satisfactory means of avoiding weak welds such as those obtained in electrolytic copper is found in the use of deoxidized copper base metal. Thus,

**Table 7—Results of Tests on Series 4 Welds**

| Mark Base and Rod | Welding Data Amps. | Volts | Speed* | Tensile Strength, PSI | Elongation in 2 Inches, % | Bend Tests Outside of Bend | 180° at 0.75 Inch R | Flat Back | Elongation in 1/2 Inch % |
|---|---|---|---|---|---|---|---|---|---|
| *P-B* | 360 | 51 | 12 | 17,670 | 6.2 | Face: | *F* at 110° | .. | 20 |
| | | | | | | Root: | *F* at 10° | .. | 0 |
| Fracture in weld. Brick red. 13% blow-holes, 7% unfused. | | | | | | | | | |
| *E-A* | 480 | 39 | 12 | 24,230 | 11.7 | Face: | *F* at 60° | .. | 28 |
| | | | | | | Root: | *F* at 10° | .. | 0 |
| Fracture in weld. Brick red. 20% porosity. | | | | | | | | | |
| *P-A* | 430 | 45 | 12 | 22,630 | 10.5 | Face: | O.K. | *F* | 20 |
| | | | | | | Root: | " | " | 30 |
| Fracture in weld. Brick red. 5% blow-hole sand unfused. | | | | | | | | | |
| *S-A* | 480 | 40 | 13 | 17,000 | 6 | Face: | *F* at 45° | .. | 14 |
| | | | | | | Root: | *F* at 60° | .. | 18 |
| Fracture in weld. 20% blow-holes. | | | | | | | | | |
| *P-F* | 370 | 50 | 12 | 24,300 | 16.8 | Face: | *F* at 60° | .. | 10 |
| | | | | | | Root: | *F* at 10° | .. | 0 |
| Fracture in weld and at edge of weld. Weld-metal unsound. | | | | | | | | | |
| *E-C* | 420 | 43 | 12 | 21,500 | 8.5 | Face: | *F* at 120° | .. | 16 |
| | | | | | | Root: | *F* at 60° | .. | 18 |
| Fracture in weld. Brick red. 20% blow-holes and unfused. | | | | | | | | | |
| *P-C* | 400 | 54 | 13 | 17,330 | 3.8 | Face: | *F* at 180° | .. | 14 |
| | | | | | | Root: | *F* at 1° | .. | 0 |
| Fracture in weld. Brick red. 37% unsound and cold lap. | | | | | | | | | |
| *S-C* | 380 | 48 | 12 | 20,070 | 5.2 | Face: | *F* at 180° | .. | 14 |
| | | | | | | Root: | *F* at 60° | .. | 12 |
| Fracture in weld. 20% unsound, 10% unfused. | | | | | | | | | |
| *E-K* | 410 | 47 | 11 | 27,530 | 17.3 | Face: | O.K. | O.K. | 50 |
| | | | | | | Root: | F at blow-holes | | 24 |
| Fracture at edge of weld and in weld. Slight porosity. | | | | | | | | | |
| *P-K* | 340 | 41 | 11 | 29,430 | 21.3 | Face: | O.K. | O.K. | 50 |
| | | | | | | Root: | *F* | .. | 16 |
| Fracture in weld and at edge of weld, about 8% unsound. | | | | | | | | | |
| *S-K* | 340 | 44 | 11 | 31,770 | 27.3 | Face: | O.K. | *F* | 36 |
| | | | | | | Root: | *F* at blow-holes | | 20 |
| Fracture at edge of weld and in weld, slight unsoundness. | | | | | | | | | |
| *E-L* | 430 | 48 | 13 | 31,270 | 21.7 | Face: | O.K. | *F* | 14 |
| | | | | | | Root: | " | " | 42 |
| Fracture at edge of weld in base metal. | | | | | | | | | |
| *P-L* | 340 | 43 | 16 | 33,400 | 33 | Face: | O.K. | *F* | 28 |
| | | | | | | Root: | " | " | 42 |
| Fracture in base metal at edge of weld and in weld. Slight unsoundness and cold lap. | | | | | | | | | |
| *S-L* | 340 | 42 | 13 | 31,970 | 36.3 | Face: | O.K. | O.K. | 32 |
| | | | | | | Root: | " | " | 32 |
| Fracture in base metal near edge of weld, sound. | | | | | | | | | |
| *E-M* | 490 | 35 | 11 | 26,400 | 16.7 | Face: | *F* at 90° | .. | 14 |
| | | | | | | Root: | O.K. | *F* | 20 |
| Fracture in base metal at edge of weld. | | | | | | | | | |
| *P-M* | 440 | 33 | 10 | 31,870 | 41.3 | Face: | O.K. | O.K. | 50 |
| | | | | | | Root: | " | " | 52 |
| Fracture in base metal near weld. | | | | | | | | | |
| *S-M* | 440 | 33 | 12 | 32,800 | 39.3 | Face: | O.K. | *F* | 36 |
| | | | | | | Root: | " | O.K. | 44 |
| Fracture in base metal near weld. | | | | | | | | | |

* Inches per minute.

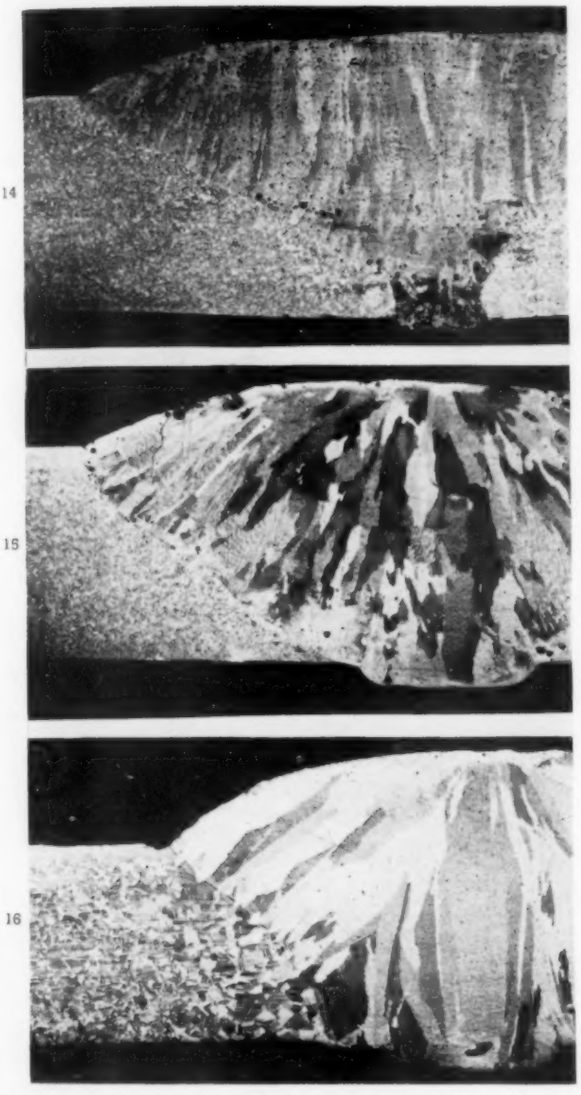


Fig. 14—Electrolytic Copper, Mark *E*, Carbon Arc Welded with Mark *C* Filler Rod

Fig. 15—Electrolytic Copper Base Metal, *E*, Carbon Arc Welded with Silicon-Manganese Bronze Filler Metal, *M*.

Fig. 16—Carbon Arc Weld, Mark *S-M*, of Table 7 Showing the Entire Freedom of Unsoundness or Other Weakness in the Silicon Deoxidized Copper Base Metal, *S*, Welded with the High Strength Silicon Manganese Bronze Filler Rod, *M*

using the same weld-metal, silicon manganese bronze, Mark *M*, with the same practice on phosphorous deoxidized copper, Mark *P*, we obtain the full strength of the soft base metal, 31,130 pounds per square inch. The weld was machined flush and no after treatment given. Figure 12 shows a macro-section of this weld. The base metal shows a 100% soundness to the fusion line. The hot gases have had no deleterious effect on it.

Figure 13 is an enlargement of the fusion zone. The sharp line of demarcation between weld-metal and base metal occasioned by the lighter color and superior hardness of the former is not so apparent in the higher magnification of Fig. 13. The grains are seen to be continuous across the fusion line indicating a true fusion weld.

What is true of the welded strength is also true of the ductility. Weld *E-M* with the bad notch effect occasioned by the weakened zone in the oxygen-bearing base metal shows only 9% elongation in the tensile tests and fails in a $^3/_4$-inch radius bend test at less than 90°.

On the other hand, the weld, *P-M*, in the phosphorous deoxidized base metal shows excellent ductility, 47.3% elongation, in the tensile test as well as a high order of ductility in the bend test in which it withstood a 180° bend and subsequent flat back without failure.

Another point of interest brought out in Table 6 is that it doesn't matter a great deal from the standpoint of welded strength as to whether the copper is deoxidized with phosphorus or silicon. The welded strength and ductility shows marked improvement in copper deoxidized with either phosphorus or silicon over that of the welded electrolytic copper.

Still another point which is brought out somewhat obscurely in Table 6 is that there is a tendency of the phosphorus containing weld-metals to develop hot short cracks while those containing silicon are comparatively free of this type of defect. Had the welds of Table 6 been run on rigidly spaced plates instead of as free welds, hot short effects in the phosphorous alloys would have been more pronounced.

## SERIES 4 WELDS

In this series of welds, the set-up of *Series 2* was employed, Fig. 2. Also, except for minor adjustments to correct the penetration, the currents and voltages of Table 3 were used. Table 7 gives the welding data and results of tests. A thin wash of 90% fused borax plus 10% sodium fluoride *flux* in alcohol was painted on welding rod and base metal.

The tensile test results are the averages of three tests on each weld while there is only one face bend and one root bend for each weld. All specimens were machined flush, i.e. weld reinforcement removed, and were tested with no after treatment:

*Remarks on Results of Series 4 Welds, Table 7.*—It should be understood that, in a number of the welds of Table 7, the heat was too low or the welding speed too high as is evidenced by the unfused or cold-lapped metal in the fractures. In particular the *P-A* and *S-A* welds should have tested higher than the *E-A* welds had the heat conditions been correct. However, it seems clear from the results of both Series 2 and Series 4 welds that the 0.06% silicon of the Mark *A* welding rod is too low to protect the metal from gas unsoundness. Applegate and Austin[17] found that approximately 0.25% of silicon was needed in the welding rod to keep the metal free of gas unsoundness in arc welding. They report the silicon as 0.12% remaining in the weld-metal. The fine porosity shown in Fig. 6 illustrates the weakness resulting from insufficient silicon deoxidizer. Figure 7, with the ample silicon of the *M* rod, shows excellent soundness and strength.

Similarly the phosphorus in the welding rods, *B*, *C* and F, is too low to protect the weld-metal from oxide and gas unsoundness in the portion of the weld exposed to the full blaze of the arc. Figure 4 is an example of this weakness. The Mark *B* welding rod having only 0.084% phosphorus left a deposit which was sound underneath where the weld-metal was melted and instantly solidified while on top, where the metal was exposed to direct arc action, it left a deposit sieve-like in character.

Figure 14, illustrating the Mark *E-C* weld of Table 7, shows the weld made up of webs of copper-cuprous oxide eutectic which fact explains the "brick red" color of the fracture as well as the low (65%) efficiency of the weld.

Figure 5 with an adequate amount of the phosphorous deoxidizer in the *L* rod fused with a phosphorous deoxidized base metal shows a deposit free of both gas unsoundness and oxides to the very top.

However, the outstanding feature of Table 7 is the ex-

cellent welded strength *and ductility* obtained with welding rods *K*, *L* and *M*. If 32,000 pounds per square inch is taken as an average strength of the three base metals, Table 5, we note that, in the deoxidized copper rods *L* and *M* develop 100% efficiency while in the electrolytic copper, they develop from 82 to 95% efficiency. Rod *K*, having a lower tin content than Rod *L*, develops a slightly lower efficiency than the latter.

The reduced efficiency of the weld made on electrolytic copper with the high strength rod, *M*, is explained by an examination of Fig. 15 of the *E-M* weld of Table 7. The normal cuprous oxide of the electrolytic copper, scattered as fine specks uniformly throughout the metal, appears, in the zone adjacent to the fusion line, to have been reduced by the carbon gases from the electrode. The result of this condition is to cause a reduction in strength below that of the weld-metal or the original base metal.

Since the element of time will give more opportunity for the migration, formation and reduction of the oxides in this zone in the base metal adjacent to the fusion line, it is clear that the passing of the welding arc should be as rapid as is consistant with good control.

Figure 16 shows that when a deoxidized copper base metal is used with a suitable welding rod, neither gas unsoundness nor oxide embrittlement is in evidence. Moreover, the element of time is not so important as there is no initial oxide in the base metal to give trouble and the protecting film of silica glass formed or the weld pool reduces the speed of further oxide formation.

## GENERAL CONCLUSIONS

While this is only a partial record of an extensive investigation, it is believed that some important points are brought out in the foregoing. Thus:

1. In any method of welding, appreciably better welded strength and ductility are obtained in deoxidized copper base metal than in tough-pitch or electrolytic copper base metal. This is true whether the base metal is deoxidized with phosphorus or with silicon.

2. The silicon deoxidized copper base metal shows better hot ductility than the phosphorous deoxidized copper.

3. In the welding rod for gas welding, the phosphorus should be low, of the order of 0.03%, while in an arc-welding rod, 0.08% is insufficient. On the other hand, 0.25% phosphorus makes a satisfactory arc-welding rod.

If silicon is used as the deoxidizer or strengthening agent in the welding rod, 0.06% is too low for arc welding and is also slightly low for insuring soundness in gas welding.

4. With *either gas or arc welding*, the *M* rod having 3% silicon, 1% manganese and the remainder copper, shows close to the maximum results in both strength and ductility.

The *L* rod, high in both tin and phosphorus, gives results as good as those of the *M* rod in arc welds but is unsatisfactory for gas welds.

5. In general, the arc welds show a higher strength in electrolytic copper base metal than do the gas welds. By and large, the gas welds can be depended upon for an efficiency of only 60% while the arc welds should develop 80%.

6. The phosphorus containing rods should be melted with a *long* arc while the silicon containing rods are preferably melted with a short arc.

7. The phosphorus containing rods can be applied only in the flat or nearly flat position while the silicon containing rods can be used to a limited degree in position welding.

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# CRATER FORMATION IN ARC Welding*

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## ABSTRACT

*Crater formation is found to be caused by the presence of oxygen in arc welding. Penetration on the contrary is a function of the rate of heat supply to the weld. Welds are made in inert gases and in mixtures of oxygen with inert gases, as well as in nitrogen and mixtures of nitrogen with inert gases. A method of correlating penetration with the welding current, independent of the rate of advance of the arc is suggested.*

*A theory of crater formation is proposed.*


## INTRODUCTION

IN ELECTRIC arc welding the base metal melts, forming a pool of liquid metal. A force of some kind seems to blast on this liquid surface continuously during welding producing a depression, technically called a crater. This crater should not be confused with penetration. The latter term means the depth of the pool of molten metal in the joint, the pool having perhaps no depression whatever in its surface. The depth of penetration can be seen only when the cross section of the weld is properly polished and etched, while the crater is visible to the operator during welding.

Crater formation is thus generally considered an essential feature of the arc welding process. What, then, are the conditions necessary to its formation? Hitherto there has been, to the best knowledge of the authors, no adequate explanation offered. Many theories concerning crater formation have been advanced by different authors, but none of them is yet fully confirmed by experimental data. The object of the present study is to investigate the conditions attending crater formation, and to try to formulate a theory that will explain the phenomenon, one upon which further improvements of the welding process may be based.

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## REVIEW OF EARLY EXPERIMENTS AND THEORIES

Early in 1920, while conducting his researches on the characteristics of regulators of the electric furnace, J. Kelleher[1] observed that there was a depression on the molten slag under the stream of the arc at normal polarity, i.e., with the moving electrode being negative. When the polarity was reversed he noticed that the arc started below the surface of the slag, the flame moving away from the slag surface and projecting particles of slag into the air with considerable force. In the same year, W. G. Duffield, T. H. Burnham and A. H. Davis[2] published the results of their experiments on the pressure upon the poles of metallic and of composite arcs. The pressure on the iron electrode was found to be a few dynes at 10 amperes current density. The atmosphere in which they performed their tests was not specified. At the end of the last decade, R. Tanberg[3] found the force of reaction of the metallic vapor on the cathode to be 0.20 gram at 11 amperes and 0.46 gram at 32 amperes. He also calculated the electrostatic and electrodynamic force acting upon the cathode to be a few dynes under his experimental condition. Creedy also published results of this nature.[3,5] P. P. Alexander[4] had investigated the energy distribution between the anode and the cathode in the welding arc. He observed that the blast of hot gases was stronger from the cathode spot; therefore, when the electrode was made negative, the blast of hot gases from the electrode is more powerful than from the anode. This resultant blast, he continued, was therefore, directed downward which caused greater heating of the metal around the positive crater. However, he did not mention any connection between this resultant blast and the crater formation.

More lately the question of crater formation has not received much attention, until in 1932 one of the present authors[5] advanced the theory that the center of the crater was the region of lowest surface tension of the liquid iron due to the higher temperature there; the metal at the center of the crater, being at higher tempera-

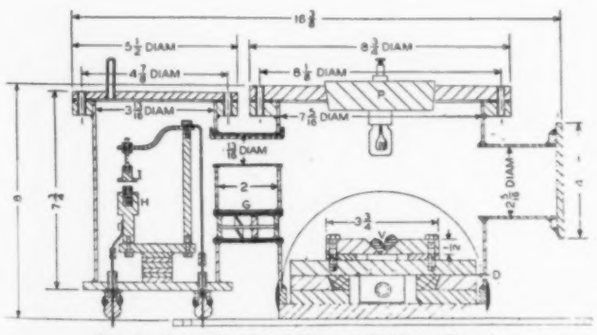



Fig. 1—Cross-Sectional View of Welding Chamber

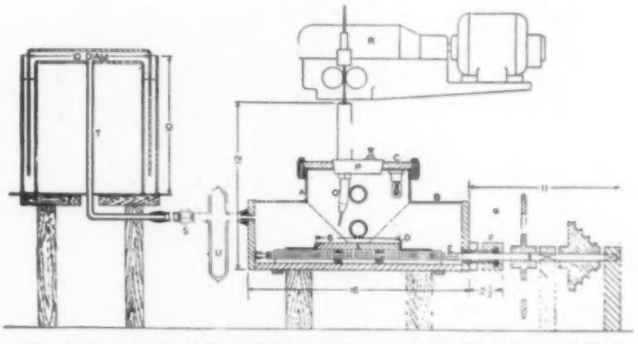
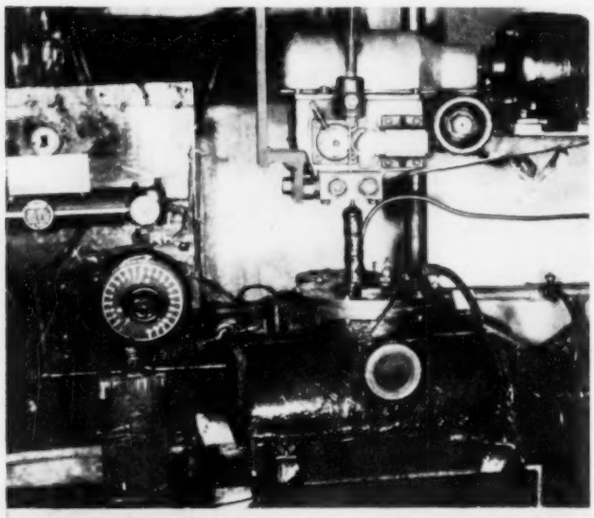


Fig. 2—Longitudinal Cross Section of Apparatus for Experimental Welding in Pure Gases—All Dimensions in Inches

Fig. 3—View Showing Chamber, Feeds and Control Panel



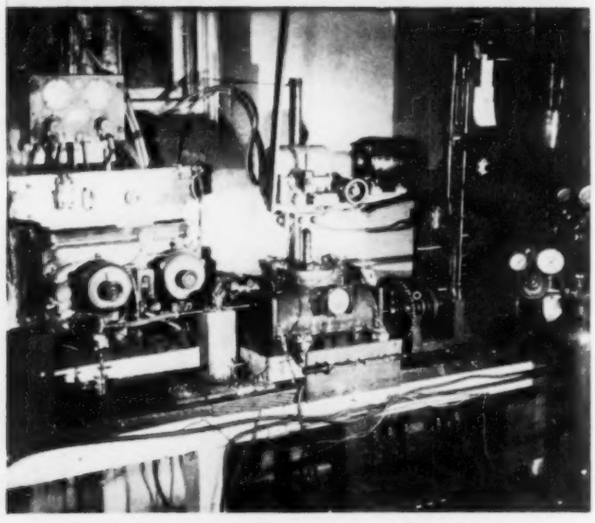


Fig. 4—View Showing Supply Tank and Glass System

ture and hence possessing lower surface tension, spread out radially to the sides thus forming a depression. He based his inference upon the experiment of W. C. Roentgen[6] in passing ether vapor over a water surface in which a depression of the water was formed where the ether concentration was greatest.

The crater phenomenon received further attention when Doan and Schulte reported their results on arc welding in argon gas.[7,8] Using pure iron as electrode and as base metal in a pure argon atmosphere, they found no crater whatever under the arc. This fact cannot be explained by any of the theories mentioned above. It was, therefore, inferred that crater formation is not an inherent characteristic of the iron arc but a phenomenon associated with the presence of air.

Dr. C. G. Suits[9,10] had found that dissociation of diatomic gas molecules such as hydrogen in the arc, and their recombination at the metal surface effected a large part of the heat transfer of the arc. He, therefore, explained the absence of crater, reported by Doan and Schulte, as due to the lack of heat transfer to the weld by the dissociation-diffusion-recombination process in the case of monatomic argon.

Space-charge pressure due to corona of several thousand volts was reported to be negligible by A. Gemant[11] recently.

These above-mentioned facts indicate that the mysterious force which causes the crater formation is not of electrical nature. Dr. Suits' theory seems to offer a new way out, but meets opposition in Doan and Bounds' work,[12] who found that there was no crater in the case of welding in hydrogen atmosphere although hydrogen is a diatomic gas, highly dissociated in the arc stream, according to Dr. Suits. Since it seems indicated in the last few paragraphs that crater formation is not primarily of electrical nature but a mechanical or chemical phenomena, attention is focused in the present study primarily on the atmosphere in which the welds are made, as described below.

## DESCRIPTION OF APPARATUS

In order to have complete control of the atmosphere in which the experimental welds were made, an air-tight chamber made of copper was used. It is fully described in reference 7. A cross-sectional view of the chamber is reproduced in Fig. 1. The larger compartment on the right is the arc chamber where actual welding is done. A glass window is provided for observation, shown at the extreme right in the picture. On the bottom of this compartment there is a carriage or movable table, *D*, which is driven back and forth by a lead-screw fitted on the lower side. A smaller compartment on the left half of Fig. 1 is called the auxiliary chamber in which a "misch-metal" arc is installed to purify the gas if necessary. The two compartments are connected to each other through two tubes as shown in the figure. Gas is introduced into the auxiliary chamber through the tube on its top cover. A longitudinal section is shown in Fig. 2 and two exterior views in Figs. 3 and 4

During welding the gas inside the chamber or passing through it is heated up and begins to expand. The gas reservoir is, therefore, provided to compensate for that change and keeps the pressure inside the chamber constant. When oxygen is mixed with an inert gas the volume may even decrease. Then the gas from the reservoir will go into the chamber. Heavy machine oil is used in the reservoir as a seal. While the chamber is being evacuated the reservoir is cut off from the system by closing a stopcock.

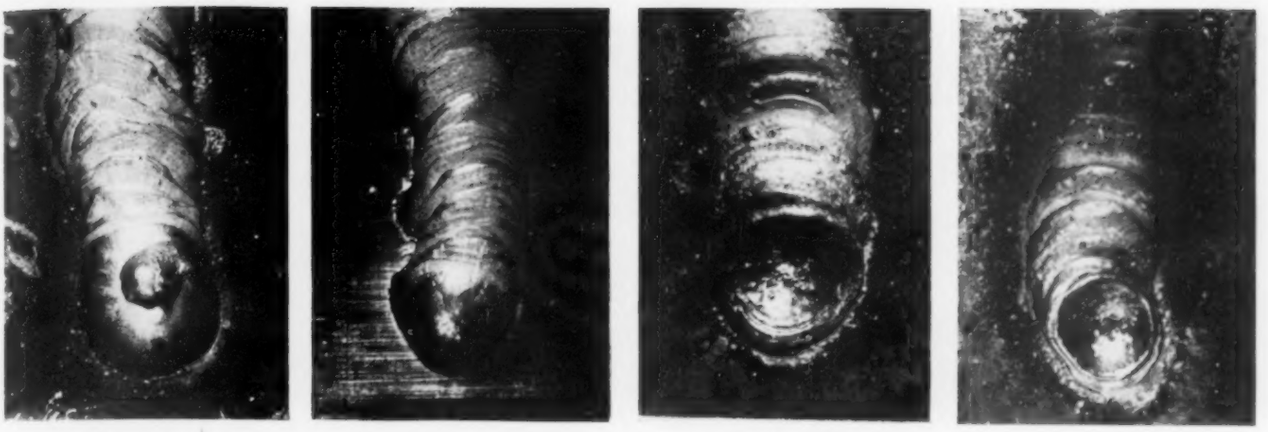
## MATERIALS

A cylinder of about 200 cubic feet of helium was supplied by the Air Reduction Sales Company for which generosity the authors are indebted. The gas was of commercial purity, 96% helium, with 3% nitrogen, $^1/_2$% methane and traces of hydrocarbon gases as impurities. Argon, 99% pure, nitrogen, 99.8% pure, and oxygen, 99.5% pure, were procured and used in the "as-received" condition.

The wire electrode was of soft steel, $^1/_8$ inch in diameter wound on a reel. The base metal was cold-rolled mild steel bar of 2 x $^1/_2$ and 2 x $^1/_4$-inch sections. High purity of the gas or of the steel was not a necessity so far as these studies are concerned. This point will be explained in a later section.

## EXPERIMENTAL TECHNIQUE

To prepare for a welding test, specimens of V-grooved or plain rectangular cold-rolled steel are bolted onto the movable table in the welding chamber. The cover plate is then tightly secured to the top of the chamber with twelve bolts. They are insulated from the cover



(*a*) in pure Helium (*b*) in Argon (*c*) in 80% He + 20% $O_2$ (*d*) in 80% A + 20% $O_2$

**Fig. 5—All Welds Made at 120 Amps., 22 Volts Across the Arc. Notice the Crater Caused by the Presence of Oxygen. Original Mag. 2.5 X**

plate by fabric sleeves and washers. In addition to the stuffing box described above, all joints are sealed off with "picein," commonly used for vacuum work.

The whole system is evacuated by an oil pump made by the Central Scientific Company capable of attaining a vacuum as low as 0.001 mm. of mercury. With the complex apparatus for arc welding, the vacuum is read to only 0.2 mm. of mercury. After half an hour of pumping the desired vacuum, 0.2 mm. of mercury, may be obtained if all of the wax joints are good. Failure to reach that condition indicates that there is leakage somewhere in the system, and a search must be made to discover it. In the section of glass tubing of the vacuum system, there are five stopcocks sealed with "vacuum grease." They remain gas-tight when grease has been properly applied and no dust gets into them. The vacuum of the glass section can be held for days or weeks without appreciable loss. Whenever there is a hair crack on the tubing it can be quickly detected with the aid of a leakage tester, and remedy is made in no time.

Much trouble comes however in maintaining a vacuum in the welding chamber on which there are eight wax joints; two of them having a circumference of more than ten inches. The leakage tester is useless here, and a blind searching method has to be used. Sometimes all the seals have to be torn down, and new ones made. It has been found by experience that the seals, except the one for the wire electrode and the one for the lead-screw which have to be broken, will remain intact if the chamber does not become too hot during welding. If only one line or one layer of weld is made the chamber becomes a little warmer than body temperature. In case several lines and layers are made, cooling water is sprinkled over the chamber in intervals to keep it cool.

The welding chamber is made of copper tubing welded together, with a rubber gasket between its top flange and the cover plate; it is by no means a vacuum-tight vessel. The vacuum loses about 1 cm. of mercury in an hour after the pump has been stopped. As soon as the desired vacuum is reached, gas or a mixture of gases is quickly and carefully introduced into the chamber, or started passing through it, and the weld is made in the shortest possible time. Thus, the pressure difference becomes nearly zero, and leakage is reduced. The time required for a single weld is one-half to four or five minutes according to the current and the size of beads.

Care is taken to insure complete control of the voltage across the arc, the speed of feeding the electrode and the speed of the work travel. The phenomena during welding are observed through the front window on the chamber. Later on the specimens are taken out, sectioned, polished and etched for thorough study.

## WELDING IN HELIUM

For $^1/_8$-inch electrode a current of 120 amperes was found by exploratory tests to make good welds. The first few welds in helium were therefore, made at 120 amperes with 22 volts across the arc. The open circuit voltage of the welding generator was 80 volts. The arc length varied from $^1/_4$ to $^1/_2$ inch long, estimated visually. Under these conditions the arc is quiet and stable. A large globule of liquid metal forms at the end of the wire and drops down like water dripping from a pipette. The so-called "pinch effect" in arc welding does not seem to work here. The molten metal deposited on the base metal merges with the metal deposited previously and assumes a *convex* spherical shape at the end of the layer. When the current is interrupted the round end swells up, forming a bump. The appearance is shown in Fig. 5 (*a*). There is no crater observed at any stage of the welding.

Then the specimen was taken out and examined. The weld had a bright metallic luster, but appeared porous, many holes being left on the surface by the excaping gas. Even under the smooth skin, blow-holes are numerous when a cross section is cut and examined. There is little penetration into the base metal although the speed of travel was varied so that the arc struck a new spot of the work piece after each drop is deposited. See Fig. 6 (*a*).

Copious black powder deposits on the inside wall of the chamber, on the base metal and on the movable table. The powder has been found by previous experiments to be alpha-iron by X-ray analysis, yielding a lattice constant of 2.861Å.

Welds at currents up to 300 amperes have also been made. No crater has been observed. The characteristics of high-current welds are discussed at the end of the paper in connection with penetration in the absence of crater.

## WELDING IN ARGON

In order to obtain a comparison with helium, welds in argon of commercial purity (99% argon) were also made at 120 amperes and 22 volts. No crater whatever was observable; the arc is stable and quiet; large globules form on the wire electrode; black powder deposits on the wall of the chamber; the end of the weld swells up, as

shown in Fig. 5(*b*), and the weld contains many blow-holes. There is a little penetration into the base metal (Fig. 6(*b*)). This slight penetration, not observed by Doan and Schulte when using pure iron, may be due to impurities in the mild steel used in the present experiment. There was, however, no crater formation whatever.

The phenomena observed in welding in helium are thus almost identical with those in argon. It appears that these inert gases behave quite similarly in arc welding. Knowing from previously reported studies that non-crater characteristics persist in argon of commercial purity as well as of high purity, the authors did not attempt to purify the helium further.

## WELDING IN HELIUM MIXED WITH OXYGEN

Since craters are absent in these oxygen-free systems, but present in air where oxygen is present, a number of welds were now made in atmospheres of helium mixed with oxygen in various proportions. The current was kept as close as possible to 120 amperes, and the arc-voltage to 22 volts, as before.

An atmosphere of 80% helium and 20% oxygen was used first. A quite definite depression in the liquid surface is noticed although the crater is not as deep as that observed in air under the same conditions. As in air the arc is accompanied by a shower of sparks. There is no large globule attached to the wire electrode but rather small drops of liquid metal rain down rapidly. After the current has been interrupted a permanent crater is left at the end of the layer, as shown in Fig. 5(*c*). The weld has a gray-colored surface and looks fairly solid. Examination of a cross section reveals a deeper penetration (Fig. 6(*c*)) than that obtained by welding in commercially pure helium (Fig. 6(*a*)). The weld is not porous but contains a few gaseous inclusions.

The oxygen content was then increased to 30%, the current and voltage across the arc being kept the same as above. The arc now cuts deeply into the base metal, penetrates the $^1/_4$-inch plate and deposits metal on the movable table beneath. The oxidation is so intense that the atmosphere in the chamber becomes densely foggy. The base metal is heated red hot. A crater is observed all the time welding is proceeding, and a permanent one is left at the end of the layer. Further increase of oxygen content in the welding atmosphere is, therefore, not advisable as the reaction will be too violent to furnish any clear view at all, and there is no doubt that thicker base metal will be cut through as in flame cutting.

An atmosphere composed of 10% oxygen and 90% helium was then used. The phenomena observed were much the same as with 20% oxygen; only the oxidation is not so fierce, and the crater and the penetration are not so deep. 5% oxygen was then mixed with helium. A crater is not distinguishable during welding, and no trace of it is left behind when the specimen is taken out. It appears that more than 5% oxygen is necessary to produce a crater. (It should perhaps have been pointed out above that in these experiments the composition of the mixture of gases is kept nearly constant by passing the mixture continuously through the chamber during welding.)

## WELDING IN ARGON MIXED WITH OXYGEN

Similar experiments were now carried out with argon-oxygen mixtures by circulating them through the welding chamber. The first mixture used was 80% argon, 20% oxygen. A crater is observed during the welding, and a permanent depression is left at the end of the layer, as shown in Fig. 5(*d*). The weld appears fairly solid. Penetration is moderate. In general, the phenomena observed are about the same as in 80% helium and 20% oxygen. The only difference is that the arc seems shorter in the argon-oxygen than in the helium-oxygen atmosphere.

It seems desirable at this point to summarize the evidence thus far concerning the influence of oxygen in crater formation. Figure 5 shows the appearance of the welds made in four different atmospheres, namely (1) commercially pure helium, (2) commercially pure argon, (3) 80% helium plus 20% oxygen and (4) 80% argon

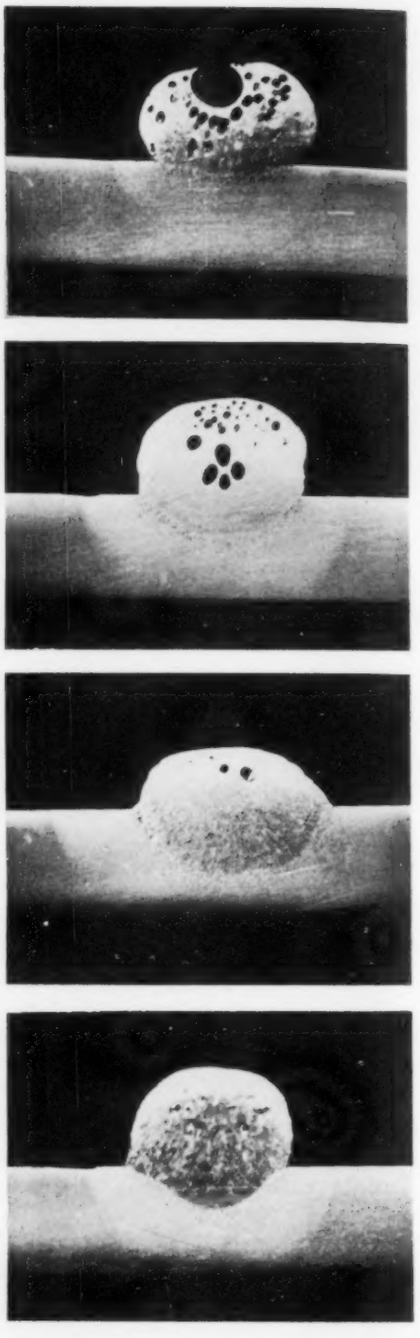



**Fig. 6—Cross Section of the Welds Shown in Fig. 5. Etched with 2% Nital, 2.4 X**

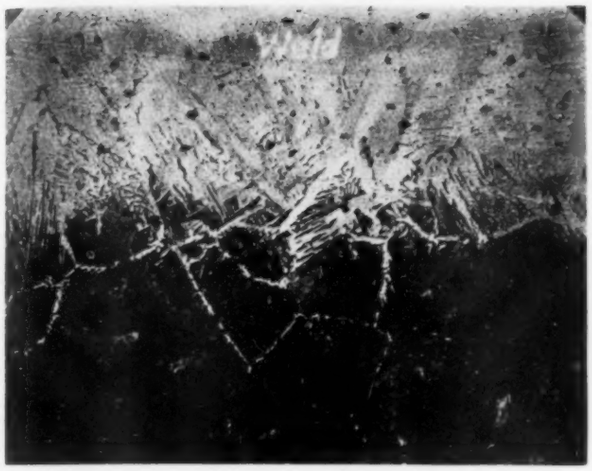


Fig. 7—From Sample (*C*), 150 X

plus 20% oxygen. The difference in crater formation caused by the presence of oxygen is obvious in Fig. 5. With regard to penetration Fig. 6 shows the cross sections of the same set of welds. It should be noted that the halo around the weld indicates the temperature gradient and thus the heat available for penetration. It will be seen that the depth of penetration, thus, is also related to the oxygen content of the atmosphere.

Figure 7 shows the junction between the deposited metal and the base metal. They have diffused into each other. All four welds in Figs. 5 and 6 have this same microscopic appearance at their junctions. The micrograph of the cross section is typical for welds. Being quenched from a high temperature, the deposited metal has a martensitic structure. The base metal immediately adjacent to the weld suffers grain growth. As the temperature gradient falls off gradually the grain size of the base metal decreases proportionally with it. Beyond a certain limit the grain size remains unaffected. In Fig. 6 the halo in the macrograph marks the range of structural transformation.

## WELDING IN NITROGEN

To determine whether or not a diatomic but non-oxidizing gas would behave differently with respect to crater formation than the mon-atomic inert ones, a number of welds have been made in nitrogen of high purity (99.8% nitrogen). The result is negative. A weld section is shown in Fig. 8. In that respect nitrogen is similar to helium and argon. On the other hand, at the same current density and arc-voltage, a weld made in nitrogen has better *penetration* than one made in pure helium or argon (compare Figs. 6 and 8). This was the *first* evidence observed in these studies that penetration could be obtained in the absence of crater.

## WELDING IN MIXED GASES

Atmospheres made up with 80% nitrogen plus 20% helium and 80% nitrogen plus 20% argon were then used for welding, other conditions being kept the same. The phenomena observed are similar to those observed in pure nitrogen, namely, no crater but moderate penetration. With 20% nitrogen plus 80% helium and 20% nitrogen plus 80% argon, the welds made therby resemble those made in pure helium and in pure argon, respectively.

## SUMMARY ON CRATER FORMATION

The results observed in connection with crater formation are compiled in Table 1 to offer a survey of the whole situation. With these data on hand it seems clear that the presence of oxygen is the cause of crater formation under these experimental conditions. Oxygen may not be the only element capable of producing crater in arc welding, but it is surely the element which causes crater formation in the case of welding in atmospheric air.

**Table 1**

| Atmosphere | Current Amps. | Arc-Voltage Volts | Open Circuit Voltage Volts | Crater |
|---|---|---|---|---|
| He | 120 | 22 | 80 | − |
| 70% He + 30% $O_2$ | 120 | 22 | 80 | + |
| 80% He + 20% $O_2$ | 120 | 22 | 80 | + |
| 90% He + 10% $O_2$ | 120 | 22 | 80 | + |
| 95% He + 5% $O_2$ | 120 | 22 | 80 | − |
| 80% He + 20% $N_2$ | 120 | 22 | 80 | − |
| A | 120 | 22 | 80 | − |
| 80% A + 20% $O_2$ | 120 | 22 | 80 | + |
| 80% A + 20% $N_2$ | 120 | 22 | 80 | − |
| $N_2$ | 120 | 22 | 80 | − |
| 80% $N_2$ + 20% He | 120 | 22 | 80 | − |
| 80% $N_2$ + 20% A | 120 | 22 | 80 | − |
| 79% $N_2$ + 21% $O_2$ | 120 | 22 | 60 | + |

Note 1. (−) sign means absence of crater while (+) sign, its presence.

Note 2. Rate of travel was adjusted for each gas to give best chance for crater to form.

## PENETRATION ,

As previously pointed out penetration is different from and does not depend upon crater formation. Its occurrence deserves careful study. To this end a series of welds has been made in helium at different currents and different arc-voltages. The current-voltage combinations are so chosen that a stable arc and a smooth weld can be obtained. (It should be emphasized that there is no crater up to 180 amperes, 25 volts across the arc and 90 volts at the open-circuit generator. Below 90 volts the arc is not stable.) The penetration increases with increasing current densities up to 150 amperes. As shown in Fig. 9 the penetration is less at 180 amperes, simply because the speed of traveling is faster. The factor of speed can be corrected for if the ratio of the depth of penetration to the radius of the outer halo is computed as illustrated in Fig. 10. Thus, calculated the extent of penetration appears to be the greatest at 180 amperes current. These ratios are tabulated in Table 2. If the ratio (P/R) in Table 2 is plotted against the square of the current, a smooth curve may be obtained as in Fig. 11. Although correction should de made for the voltages. This ratio (P/R) may be considered as the rela-

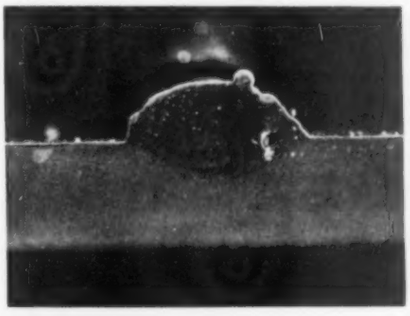
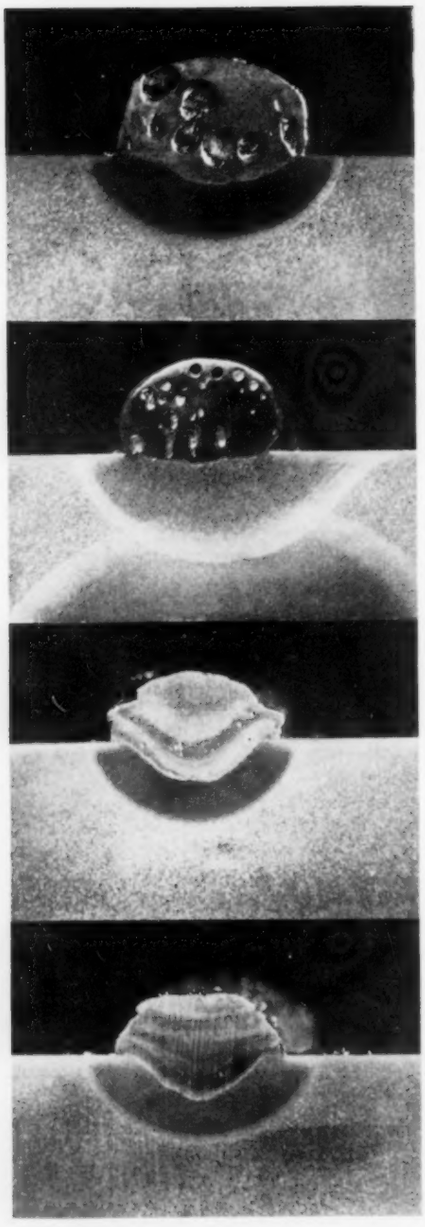


Fig. 8—Weld Made in $N_2$, No Crater, Moderate Penetration



(a) Current 90 amps. arc-voltage 20 volts

(b) Current 120 amps. arc-voltage 22 volts

(c) Current 150 amps. arc-voltage 22 volts

(d) Current 180 amps. arc-voltage 25 volts

**Fig. 9—All Welds Made in Helium with 90 Volts Open-Circuit Voltage**

**Table 2**

| Current (I) Amps. | Penetration (P) Mm.* | Radius of Halo (R) Mm.* | Ratio (P/R) | $(I)^2$ |
|---|---|---|---|---|
| 90 | 2 | 16 | 0.125 | 8100 |
| 120 | 6 | 20 | 0.300 | 14400 |
| 150 | 9 | 25 | 0.360 | 22500 |
| 180 | 6.5 | 17 | 0.382 | 32400 |

* Measurements made on macrographs.

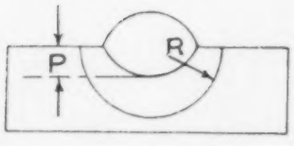



**Fig. 10—Penetration (P), Radius of Halo (R)**

tive penetrating power of different currents at the same length of time for heat flow.

The evidence is sufficient to indicate that penetration may be secured without the presence of a crater, although the latter is always favorable for the former. The common belief that crater formation is essential for penetration is, therefore, disproved. It should be remarked here that nitrogen does not cause crater formation primarily nevertheless it aids penetration.

## INTERPRETATION OF RESULTS

There are several possible reasons why oxygen causes a crater to form: (1) Oxygen oxidizes liquid iron forming an oxide solution on the surface of the globule and on the surface of the liquid pool beneath it. This oxide solution probably lowers the surface tension of the liquid metal. The fact that very small drops but no large drops are formed on the end of the electrode when oxygen is present indicates, but does not prove, that the surface tension of the steel is definitely lowered by the presence of oxygen.

The simplest explanation of the entire crater phenomenon would thus be that the blast coming continuously from the electrode strikes this pool of liquid metal having a low surface tension due to its oxide content, and blows it out of the hotter center thus producing a depression or a crater. When the oxide solution is absent as in the inert gas atmospheres the blast has the same striking force but is unable to produce a crater in the oxygen-free and therefore high-surface-tension liquid steel. With only 5 per cent oxygen present the solution is not formed or is too dilute due perhaps to removal of oxygen from the atmosphere by the scavenging action of the iron vapor before it reaches the pool. With 30 per cent oxygen the cratering effect is marked, both due to low surface tension of the liquid and due to thermo-chemical heating and actual burning, as with the oxyacetylene torch.

It is quite possible, of course, that the force of the blast may change also with change in the arc atmosphere.

The concentration gradient of oxygen from the center of the crater toward its edges might be expected to give a high-oxygen region at the center. The spreading effect of the material in this region unaided by any blast might produce a depression as in the ether-water experiment of Roentgen. At these very high temperatures, however, such as those which probably obtain at the center of the crater, iron oxide may on the contrary dissociate more rapidly than it forms. Nevertheless, it is conceivable that both the oxygen concentration gradient and the temperature gradient working together may produce the depression without the aid of the blast. In either case, however, crater formation would depend upon a lowered surface tension of the liquid metal in the pool.

The *penetration* phenomena can be treated as due to simple heat flow. The lines of temperature gradient, or isotherms, are clearly revealed on the etched cross section of the weld. They assume approximately the form of spherical waves. Referring to Figs. 6 and 9, the curved line between the deposited metal and the base metal indicates that the temperature has reached the melting point of the steel, 1500° C., at this line. The limit of the halo marks the range of grain growth which occurs at a definite temperature for certain kind of steel, probably about 700° C. for this steel. Down to the 1500° line the steel melts, mixes with the deposited metal and leaves a line of penetration afterward. There is no doubt that crater action also facilitates a more rapid

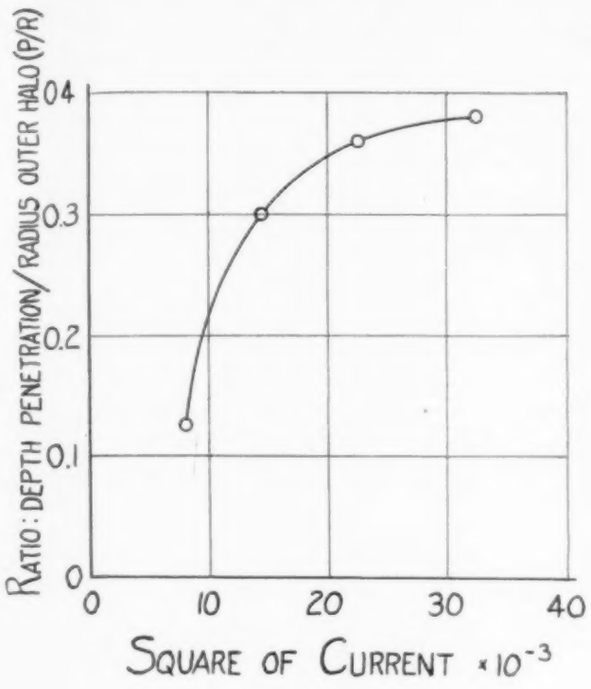



Fig. 11—Plotted from Table 2

penetration by digging into the base metal and reducing the depth of the liquid pool through which the heat must flow. But if a sufficient supply of heat is provided a crater is not necessarily required to effect penetration. As proved in the present experiment, this large amount of heat may be derived from high currents. Thus, as shown in Fig. 9, good penetrations are obtained by welding in helium where there is no crater observed. The fact, that welds made in nitrogen at 120 amps. have better penetration and yet in the absence of a crater, may be due in part to the explanation of Suits: the diatomic molecules of nitrogen transmit the heat, developed in the arc, to the base metal more effectively by the dissociation-diffusion-recombination process while the monatomic helium or argon are poor carriers of heat, and welds made in them have consequently less penetration than those made in nitrogen at the same current. Also the positive crater may be hotter in $N_2$ than in He or Argon.

Since penetration is a function of heat supply it is, therefore, a function of temperature and time. No matter how high the temperature of the arc, sufficient time must be allowed for the heat to flow into the metal if penetration is to result. The decrease of penetration at 180 amperes in helium occurs because the base metal travels so fast, due to the rapid melting of the wire electrode. It should be noted that not only the penetration falls off but also the range of grain growth at this high current, due to the increased speed of travel. The ratio of the depth of penetration to the radius of the halo is a measure of the relative penetrating power of the different currents at approximately the same length of time for heat flow. This result is best represented by the curves in Fig. 11.

## CONCLUSIONS

1. The presence of oxygen, both in air and in inert gases, permits crater formation in metallic arc welding. The mechanism probably is a lowering of the surface tension of the liquid iron by solution of oxygen or iron oxide in it.

2. Penetration can be obtained in the absence of crater by (*a*) using a diatomic gas, nitrogen, as atmosphere, and (*b*) by using high currents with inert gases.

## ACKNOWLEDGMENTS

The assistance of the Welding Research Committee of Engineering Foundation in procuring rare gas supplies for these experiments is gratefully acknowledged.

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# RESIDUAL STRESSES DUE TO Circumferential Welds in Pipes*

By E. L. ERIKSEN† and I. A. WOJTASZAK†

TESTS‡ were made on a series of three welded specimens of 20 inch O.D. pipe with 1-inch wall thickness and four welded specimens of 8 5/8 inch O.D. pipe with 1/2-inch wall thickness for the purpose of establishing the variation in the residual stresses produced primarily by stress relieving but also by other differences in the history of the specimens. The specimens were all 18 inches long, consisting of two 9-inch lengths of pipe joined together by a circumferential electric arc weld as shown in Fig. 1. All pipes were open-hearth, seamless steel with carbon content not over 0.30%. Three of the specimens were stress relieved at 1200° F. for 8 hours. A summary of the specimens follows:

| Specimen No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Pipe Size (O.D.) | 20 in. | 20 in. | 20 in. | 8 5/8 in. | 8 5/8 in. | 8 5/8 in. | 8 5/8 in. |
| Wall Thickness | 1 in. | 1 in. | 1 in. | 1/2 in. | 1/2 in. | 1/2 in. | 1/2 in. |
| Stress Relieved | Yes | No | No | Yes | No | Yes | No |

Results of these tests are tabulated in the following table giving only max. values of longitudinal and circumferential stresses.

| No. of Specimen | Outside Diameter | Wall Thickness | Stress Relieved | Max. Longitudinal Stress | Max. Circumferential Stress |
|---|---|---|---|---|---|
| 1 | 20 in. | 1 in. | Yes | ± 8,500 lb./in.² | 4,000 lb./in.² |
| 2 | 20 in. | 1 in. | No | ±50,000 lb./in.² | 32,000 lb./in.² |
| 3 | 20 in. | 1 in. | No | ±45,000 lb./in.² | 26,000 lb./in.² |
| 4 | 8 5/8 in. | 1/2 in. | Yes | ± 3,500 lb./in.² | 2,500 lb./in.² |
| 5 | 8 5/8 in. | 1/2 in. | No | ±24,000 lb./in.² | 17,000 lb./in.² |
| 6 | 8 5/8 in. | 1/2 in. | Yes | ± 5,000 lb./in.² | 3,500 lb./in.² |
| 7 | 8 5/8 in. | 1/2 in. | No | ±25,000 lb./in.² | 13,000 lb./in.² |

+ Indicates tension.
± Indicates tension or compression.

In order to determine the circumferential residual stresses, one-half of the pipe specimen with circumferential weld shown in Fig. 1 is first laid out into a number of rings as shown by dotted lines 0–0′, 1–1′, . . . 5–5′. Reference marks are carefully made at the ends of two perpendicular diameters of each ring (see Fig. 2) and the distances $d_1$ and $d_2$ are measured, from which the mean diameters $d_{1m}$ and $d_{2m}$ of the ring in the directions $d_1$ and $d_2$ are determined. The mean diameter of each ring is then

$$d_m = \frac{d_{1m} + d_{2m}}{2} \tag{1}$$

We now begin to release the circumferential residual stresses in the pipe by cutting it up into rings along the lines 0–0′, 1–1′, . . . 5–5′ (see Fig. 1). The new distances $d_1'$ and $d_2'$ are now measured for each ring and we determine the new mean diameters $d_{1m}'$ and $d_{2m}'$ in the directions $d_1'$ and $d_2'$. The new mean diameter of each ring is given by the formula

$$d_m' = \frac{d_{1m}' + d_{2m}'}{2}$$

The circumferential residual stresses released thus far are found from the equation

$$S_1 = E\frac{\Delta d_m}{d_m} \tag{2}$$

where $\Delta d_m = d_m' - d_m$. These stresses are either direct compressive or direct tensile stresses.

We can still further release the circumferential residual stress in each ring by slitting it open as shown in Fig. 3. The stresses released in this manner are caused by a moment $M$ which is given by the equation[1]

$$\frac{1}{d_m''} - \frac{1}{d_m'} = -\frac{M}{2EI} \tag{3}$$

where

$$d_m'' = \frac{d_{1m}'' + d_{2m}''}{2}$$

while

$I$ = the centroidal moment of inertia of the slit section of the ring.
$M$ = the moment, applied to the slit ends of the ring shown in Fig. 3, which is required to open the ring.

Having the value $M$ found from Eq. (3), the magnitude of the circumferential residual stress at the extreme fibers of the ring is

$$S_2 = \pm Eh\left(\frac{1}{d_m''} - \frac{1}{d_m'}\right) \tag{4}$$

where $h$ is the thickness of the pipe wall. Since the stress $S$ is caused by a moment, it is tension at the inner wall and compression at the outer wall (or vice versa). The total circumferential residual stress is found from Eqs. (2) and (4) to be

$$S = S_1 = S_2 \tag{5}$$

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† University of Michigan, Ann Arbor, Michigan.
‡ These tests were made through the Department of Engineering Research, University of Michigan for Philadelphia Electric Company.

[1] See Strength of Materials, 2, p. 459, by S. Timoshenko ,1930.

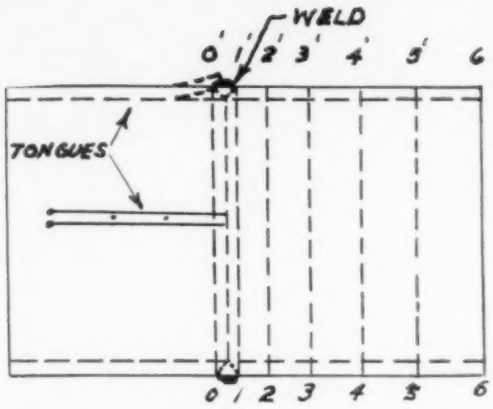

Fig. 1

The determination of the longitudinal residual stresses is much more difficult and uncertain than that of the circumferential residual stresses. Imagine a narrow ring including the weld and a portion of the pipe metal to be at a temperature of molten steel while the rest of the pipe is at room temperature. When this hot ring cools, it will tend to shrink but since it cannot shrink freely due to the adjacent pipe metal, it will set up longitudinal stresses in the pipe due to bending of the pipe wall, similar to those which would be set up by a narrow ring shrunk onto the pipe. The longitudinal stresses set up in this manner can be found by applying the theory of a beam on an elastic foundation.

In order to apply the theory of a beam on an elastic foundation in the determination of longitudinal residual stresses in pipes due to welds, the following technique was used. Tongues were sawed in the walls of the pipe as shown in Fig. 1. These tongues were 7 inches long and about $^1/_4$ of an inch wide. Readings were taken to find the amount of deflection at the free end of the tongue after the tongue was sawed out.

Taking the origin of coordinates at the free end of the tongue which coincides with the center of the weld as shown in Fig. 4, the equation of the deflection curve is[2]

$$y = \frac{P_o}{8\beta^3 EI} e^{-\beta x} (\cos \beta x + \sin \beta x) \qquad (6)$$

while the moment is given by the equation

$$M = -EI \frac{d^2y}{dx^2} = -\frac{P_o}{4\beta} e^{-\beta x} (\sin \beta x - \cos \beta x) \qquad (7)$$

where $-\frac{P_o}{2}$ = shear in tongue for $x = 0$

$M_o$ = moment at $x = 0$
$y$ = deflection of the tongue, for any value of $x$, taken positive when downward
$E$ = modulus of elasticity
$I$ = centroidal moment of inertia of cross-sectional area of the tongue
$e$ = base of natural logarithms (= 2.7183)
$\beta = \sqrt[4]{\frac{3(1-\mu^2)}{r^2h^2}}$
$\mu$ = Poisson's ratio (taken equal to 0.3)
$r$ = mean radius of the pipe
$h$ = thickness of pipe wall.

From Eq. (7) we find, by putting $x = o$

$$\delta = (y)_{x=0} = \frac{P_o}{8\beta^3 EI} \qquad (8)$$

and from Eq. (7)

$$M_o = \frac{P_o}{4\beta} \qquad (9)$$

As mentioned previously, readings were taken to determine the deflection of the free end of the tongue, i.e., $(y)_{x=0} = \delta$. Substituting this value of $(y)_{x=0}$ into Eq. (8) we determine the magnitude of $P_o$ and then Eq. (9) yields the value of $M_o$.

In determining residual stresses we are, of course, primarily interested in the maximum value of these stresses. It is found from Eq. (7) that $M_o$ is the maximum value of $M$ and so we use $M_o$ in determining the maximum longitudinal residual stress.

Thus, the maximum longitudinal residual stress is

$$(S_l)_{max.} = \frac{M_o h}{2I} \qquad (10)$$

If we wish to consider the reinforcing effect of the surplus metal of the weld, i.e., the portion of the weld-metal extending beyond the outer wall of the pipe, we may determine the longitudinal residual stress on the basis of the moment $M$ acting at the edge of the weld. If the average width of the weld is $a$ and stress concentration is neglected, then the maximum longitudinal residual stress would be given by

$$(S_l)_{max.} = \frac{h(M)_{x=a/2}}{2I}$$

where $M$ is given by Eq. (7).

## LABORATORY PROCEDURE OF TAKING DATA FOR THE DETERMINATION OF RESIDUAL STRESSES IN PIPES DUE TO WELDS[1]

One-half of each specimen was laid out into rings, 0–0′, 1–1′, ...5–5′ as shown in Fig. 2 and at the ends of two perpendicular diameters of each ring, small screws, with protruding heads, were inserted. The protruding screw heads contained reference marks used for the purpose of taking measurements.

All measurements were taken with the aid of microscope micrometers reading to 0.001 mm. These microscope micrometers were attached to a heavy steel plate and thus were fixed in position a certain distance apart so that only the micrometer slides were movable. The pipe specimens were placed in saddles which allowed the reference points upon which the microscope micrometers

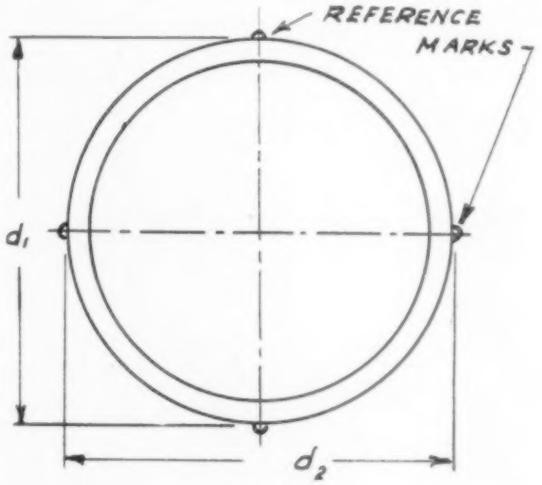

Fig. 2

[1] See Strength of Materials, pp. 404 and 517, by S. Timoshenko, 1930.

were focused to slide back and forth under the microscope micrometers. Not less than five readings of each reference point were taken and the mean of these values used. Also for each position of the reference points at least two independent sets of readings were taken and the results of these two sets of readings were averaged. The fixed distance $d_o$ between parallel cross-hairs of the micrometer microscopes when the micrometer reading was zero was obtained by focusing them on the marks of a steel scale. A slight error in measuring this fixed distance $d_o$ would affect the results but very slightly.

Figure 5 shows the position of the reference marks relative to the microscope micrometers when readings are being taken. The four reference marks on each ring are identified by the four letters $A$, $B$, $C$, $D$, while the subscript of each set of letters gives the number of the ring. For the set-up as shown in Fig. 5, we set the cross-hairs of the microscope on the reference marks $A_1$ and $C_1$ and read the micrometers. Thus, the distance $A_1C_1$ between the reference marks is equal to the sum

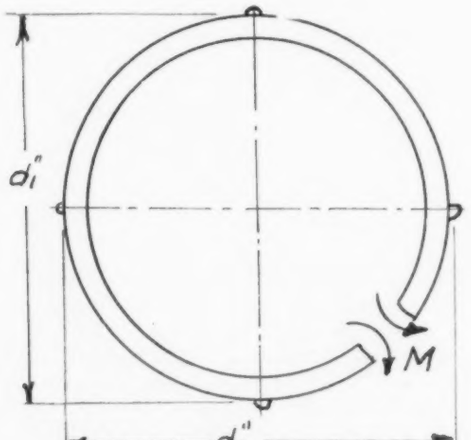


Fig. 3

of the two micrometer readings and the fixed distance $d_o$ between the cross-hairs of the microscope micrometers when the micrometers are set at zero. By measuring the distance of the reference mark from the outside surface of the pipe and the thickness of the pipe wall we can find the mean diameter of the pipe for the given positions.

On the left half of the pipe shown in Fig. 1, tongues were laid out parallel to the axis of the pipe. The longitudinal axes of these tongues were in axial planes of the pipe making an angle of 90° with each other and reference marks at the ends of two perpendicular diameters were used for this case as were for the case of the rings explained above (see Fig. 5). On some of the pipes additional reference marks were provided on the tongues to determine their longitudinal deformation.

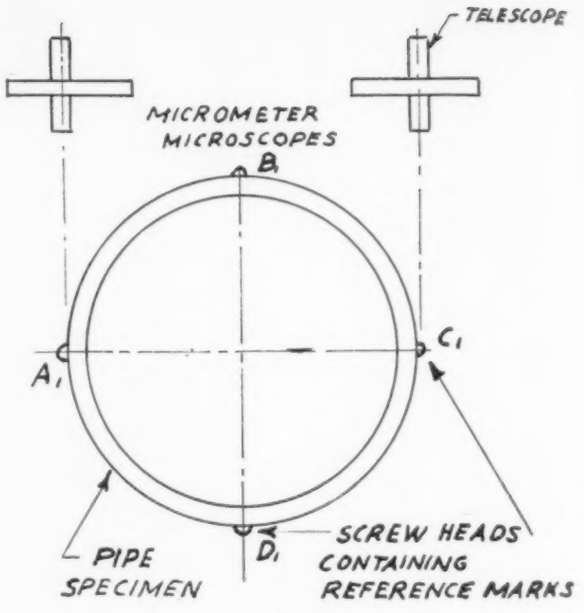


Fig. 5

After all the initial microscope micrometer readings were taken the right half of the pipe specimens were cut into rings along the lines 0–0′, 1–1′, . . .5–5′ (see Fig. 1) while tongues were sawed in the left half and the readings on all the reference points repeated. The rings were now slit open and a third set of readings taken on these reference points.

## CONCLUSIONS AND REMARKS

Probably the most important conclusion to be drawn from the results found in the above table is that the residual stresses are decidedly lowered by stress relieving at 1200° F. It is to be remarked in this connection that tests by other investigators on 0.20% carbon steel show that stress relieving at 1200° F. tends to increase the ductility about 50% and lower the ultimate strength about 30%.

It may be mentioned that the magnitude of the circumferential stresses given in the above table is quite possibly more accurate than that of the longitudinal stresses. The circumferential stresses were obtained by simply transforming the elastic recoveries into stress, while a more complicated theory was assumed in the calculation of the longitudinal stresses.

It is also disturbing to the investigator to find longitudinal stresses of 50,000 lb./in.$^2$, a stress that is beyond the yield point of the pipe material as well as the weld material. This may indicate that the calculations of the longitudinal stresses mean very little or it may mean that there has been quite a considerable stress locked up in the original pipe before welding or that a certain amount of strain hardening has taken place.

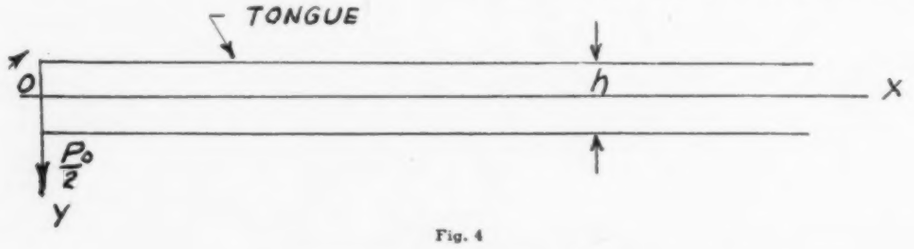


Fig. 4

In order to get a more definite picture of the stresses set up by the actual welding process, it seems necessary that a much more comprehensive study should be made including an investigation of the original residual stresses in the pipe.

And finally suppose the 50,000 lb./in.$^2$ stress simply means that the material at some place has passed beyond the yield point; how serious is this?

This will depend on the use of this pipe; if it is subjected to steady or static stress, it will probably not be serious; if however, it is subjected to fluctuating stress it may have serious results.

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# Hard Surfacing with White Alloy Cast-Iron and Copper-Nickel Alloys Containing Tin

By M. BALLAY and R. CHAVY*

AN ALLOY for hard-facing must possess a variety of special properties, for example, its melting point must not differ too much from that of base metal, the metal must flow readily, must adhere well, and must be free from cracks, blow-holes and other defects.

White cast iron has been used for hard surfacing but has never been promising because the hardness was too low, even if the iron were alloyed with chromium. On the other hand, the martensitic nickel-chromium cast irons are much harder. The hardness of white cast iron depends on the carbide content, the hardness of the carbide and the hardness of accompanying constituents, such as pearlite, sorbite, martensite or austenite. Nickel and chromium have little influence on the hardness of the carbide, but they promote the formation of martensitic structures of maximum hardness.

* Paper presented before International Foundry Congress, Paris, 1937; extended abstract by B. Trautmann in *Autogene Metallbearbeitung*, **31** (13) 214–217, July 1, 1938.

The tests carried out by Ballay and Chavy involved thin rods cast in dry sand molds. Mild steel and pearlitic cast iron were used as base metal. After the surface to be covered had been slightly preheated, the spot to be surfaced was heated to the melting point with the welding torch. The rod coated with flux was then introduced into the welding flame, and was deposited drop by drop on the fluid surface. A second layer was deposited using the same technique. A carburizing flame was used with steel in order rapidly to carburize the surface and lower the melting point, thus securing better bond. This procedure did not change the structure of the surface layer of gray cast iron, which remained gray after surfacing. Hardness was measured with a Vickers diamond pyramid under 50 kg. load, Table 1.

The use of common white cast iron with relatively high silicon content led to a mottled structure on mild steel and a gray structure on gray cast iron. With lower silicon in the rod the deposit was white and over 450 Brinell. Cast iron containing chromium and relatively high silicon also yielded a mottled deposit. Again with lower silicon the deposit was completely white and 500–525 Brinell.

With white Cr-Ni cast iron deposited on mild steel a hardness above 600 Brinell is attainable. Adherence is very good, notch impact specimens exhibiting cracks in the hard surface but no peeling. The microscopic appearance of the junction zone suggested perfect bond with a martensitic band about 0.005 inch wide. Since increasing amounts of nickel and chromium cause the appearance of austenite, the hardness decreases (No. 10, Table 1).

Tests were made to determine the effect of heat treatment. The following results were attained with

**Table 1—White Cast-Iron Rods Deposited on Mild Steel and Pearlitic Gray Cast Iron**

| No. | Rod | Composition of Surface, % | | | | | Mild Steel Base Metal | | Pearlitic Gray Cast-Iron Base Metal | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Total C | Mn | Si | Ni | Cr | Brinell Hardness of Surface | Number of Layers | Brinell Hardness of Surface | Number of Layers |
| 1 | Ordinary cast iron | 3.27 | 0.72 | 1.66 | 0.10 | .. | 425 | 2 | 259 | 2 |
| 2 | Ordinary cast iron | 3.17 | 0.38 | 0.97 | 0.08 | trace | 430 | 3 | 464 | 3 |
| 3 | Chromium cast iron | 3.57 | 0.86 | 1.88 | ... | 1.49 | 495 | 2 | 500 | 2 |
| 4 | Chromium cast iron | 3.10 | 0.46 | 0.80 | 0.08 | 1.56 | 500 | 3 | 510 | 3 |
| 5 | Chromium-nickel cast iron | 3.14 | 0.73 | 1.31 | 1.98 | 1.45 | 525 | 2 | 463 | 2 |
| 6 | Chromium-nickel cast iron | 3.10 | 0.58 | 0.85 | 3.05 | 1.42 | 635 | 3 | 610 | 3 |
| 7 | Chromium-nickel cast iron | 3.40 | 0.59 | 1.10 | 2.28 | 1.50 | 610 | 3 | 593 | 3 |
| 8 | Chromium-nickel cast iron | 3.61 | 0.65 | 0.73 | 1.08 | 1.80 | 595 | 2 | 580 | 2 |
| 9 | Chromium-nickel cast iron | 3.01 | 0.74 | 1.31 | 2.90 | 1.39 | 615 | 2 | 463 | 2 |
| 10 | Chromium-nickel cast iron | 2.67 | 0.55 | 1.48 | 3.98 | 2.07 | 405 | 3 | 497 | 3 |
| 11 | Austenitic Cr-Ni cast iron | 3.18 | 0.76 | 1.49 | 10.30 | 5.02 | 460–470 | 2 | 465 (492) | 2 (or 1) |

**Table 2—White Cast Iron or Stellite Deposited on Austenitic Cast Iron or Steel**

| No. | Base Metal | Rod | Composition of Deposit, % Total C | Mn | Si | Ni | Cr | Brinell Hardness of Surface | Number of Layers |
|---|---|---|---|---|---|---|---|---|---|
| 12 | Austenitic gray cast iron | White Cr-Ni cast iron | 3.40 | 0.59 | 1.10 | 2.28 | 1.50 | 638 | 3 |
| 13 | Austenitic gray cast iron | White austenitic cast iron | 3.18 | 0.76 | 1.49 | 10.30 | 5.02 | 463 | 3 |
| 14 | 13% Mn steel | White Cr-Ni cast iron | 3.14 | 0.73 | 1.31 | 1.98 | 1.45 | 590 | 2 |
| 15 | Mild steel | Stellite | .. | .. | .. | ... | .. | 540–570 | 2 |

a rod containing 3.1 total C, 0.58 Mn, 0.85 Si, 1.42 Cr, and 3.05 Ni.

| | |
|---|---|
| Not heat treated | 635 Brinell |
| Held 15 min. at 825° C., air cooled | 670 Brinell |
| Held 15 min. at 825° C., oil quenched | 660 Brinell |

With pearlitic gray cast-iron base metal a very adherent surface of 460–610 Brinell was secured. The low thermal conductivity of the gray cast iron and the presence of graphite, which favors mottled structure, must be borne in mind in hard-facing gray cast iron. Austenitic gray cast-iron base metal is easily hard surfaced with Cr-Ni cast-iron rods (No. 12. Table 2).

Coatings of austenitic white cast iron on mild steel have uniform hardness (460–470 Brinell) and the structure of the junction zone is practically free from graphite. Uniform hardness is secured with the austenitic rods of pearlitic gray cast iron, but, as with the martensitic rods, the junction zone contains graphite. There is no difficulty in depositing adherent surfaces of the austenitic rod on austenitic cast-iron base metal.

Alloys with 5–15 Sn, 50–60 Ni, rem. Cu, are principally used for valves and fittings for superheated steam. Their structure is similar to ordinary high-tensile bronzes. The Cu-Ni-Sn alloys have better frictional properties than Cu-Ni alloys and resemble bronzes. The hardness is 250–350 Brinell and is not greatly changed up to 500° C. The following alloys were used in the welding tests.

(*a*) 2.5 Si, 8 Sn, 39.5 Cu, 50 Ni
(*b*) 3.5 Si, 4 Sn, 27.5 Cu, 65 Ni

Both alloys were 350 Brinell at room temperature and 315–320 Brinell at 450° C. A reducing flame was used with a tip 0.32 inch diameter. Anhydrous boric acid was used as flux. Porosity is decreased by adding manganese to the alloys. An oxidizing flame yields unsatisfactory deposits. The technique was the same as with cast-iron rods. Results are summarized in Table 3.

With Monel Metal (120 Brinell) as base metal, an extremely tenacious surface (450 Brinell) is obtained. On soft steel the adherence is very good and the hardness is 420 Brinell. On account of the small difference in melting point between the bronze and pearlitic gray cast iron, surfacing is easy to perform, but the presence of graphite creates large variations in hardness. Uniformity of hardness is secured by depositing several layers, which is also true with austenitic gray cast-iron base metal.

## SUMMARY

The flame must be carburizing for both white cast-iron and bronze rods. A large tip is essential. On mild steel base metal two layers 0.12–0.16 inch thick are usually adequate. On cast iron three layers 0.20–0.24 inch thick should be deposited. To prevent distortion of the part to be surfaced it should be preheated. Costs are low for both types of rods.

Two compositions are recommended for white, martensitic Cr-Ni, cast-iron rods:

1. 3.5–3.8 total C, 0.7–1 Si, 0.5–0.8 Mn, > 0.2 P, 1.8–2 Cr, 1.5–2 Ni.
2. 2.8–3 total C, 0.7–1 Si, 0.5–0.8 Mn, > 0.2 P, 1.8–2 Cr, 2.8–3.2 Ni.

The nickel content must be adjusted to suit the carbon content in order to attain maximum hardness. These rods should be used for maximum wear resistance; for example, hammers, parts of milling apparatus, valves, guides, dredges, conveyor equipment, etc.

White, austenitic Cr-Ni cast-iron surfaces are softer but less brittle than the martensitic type. Their chief use is for chemical and petroleum equipment in which corrosion resistance in HCl, $H_2SO_4$, and mixtures of $H_4SO_4$ and $HNO_3$ is important. The following composition is usually best.

3. 3–3.3 total C, 0.7–1 Si, 1–1.5 Mn, 0.2 P, 4–6 Cr, 8–12 Ni.

Coatings of Cu-Ni alloys containing tin and silicon are hard and ductile, and have good resistance to corrosion and oxidation. The following compositions are recommended.

1. 1–1.5 Mn, 3–3.2 Si, 5–6 Sn, 50–60 Ni, rem. Cu.
2. 1–1.5 Mn, 4–5 Si, 5–6 Sn, 50–60 Ni, rem. Cu.

Several layers should be deposited on cast iron to prevent graphite inclusions. These rods are difficult to apply to brass or bronze whose melting points are too low and whose thermal conductivity is too high. The Cu-Ni surfaces are excellent for valves, valve seats, pump parts, and all applications in which absence of seizure at high pressures and temperatures is essential. The Cu-Ni surfaces have been successful as valve seats of internal combustion engines.

**Table 3—Copper-Nickel Alloys Containing Tin and Silicon used for Hard Facing**

| No. | Base Metal | Composition of Deposit, % Cu | Ni | Sn | Si | Brinell Hardness of Deposit | Number of Layers |
|---|---|---|---|---|---|---|---|
| 16 | Monel metal | 36.2 | 50.5 | 4.9 | 5.8 | 420 | 2 |
| 17 | Monel metal | 37.1 | 48.9 | 7.0 | 4.9 | 405 | 2 |
| 18 | Mild steel | 36.2 | 50.5 | 4.9 | 5.8 | 423 | 2 |
| 19 | Pearlitic gray cast iron | 37.1 | 48.9 | 7.0 | 4.9 | 360 | 2 |
| 20 | Austenitic gray cast iron | 37.2 | 49.1 | 5.2 | 4.95 | 413 | 3 |